INDUSTRIAL HEALTH ENGINEERING

INDUSTRIAL

HEALTH

ENGINEERING

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PREFACE

Industrial health, or industrial hygiene as it is commonly called, is concerned with the prevention of occupational diseases and the maintenance of the health of industrial workers on a high level. It requires the combined efforts of a variety of professional personnel, most important of which are engineers, physicians, chemists, and nurses. The industrial physician and nurse are concerned with the well-being of the worker, while the industrial health engineer and chemist are concerned with the condition or "well-being" of the worker's environment. The entire program is preventive rather than curative in nature. The physician, through medical examination of the workers, and the chemist or engineer, through studies of the atmosphere, evaluate or determine the hazardous operations or locations. If hazards are found, or are known to exist, it becomes the duty of the engineer or chemist to work with the plant engineering department on the control or elimination of them. Not infrequently, the industrial health engineer or safety engineer, who has specialized in industrial hygiene, is called upon to determine what control steps should be taken and to design the control equipment.

Industrial health engineering might be defined as the science of maintaining the worker's environment in a condition conducive to good health, that is, keeping all harmful environmental exposures away from the workers. Even though this branch of engineering is fundamentally a science, it appears to be an art as practiced today in many industries.

Industrial health engineering as a profession is relatively new, having come into existence largely in the period between the first and second world wars. In its broad sense it combines certain phases of sanitary engineering, chemical engineering, industrial engineering, and mechanical engineering into one profession, and for this reason it is not generally recognized as a distinct profession. At the present time, industrial hygiene engineering has not been established in any school of college grade as a standard four-year course or even as an optional two-year course following two years of generalized education in suitable basic engineering subjects. Graduate courses in in-

dustrial hygiene, running anywhere from three months to two years, are given by several colleges and universities to men having degrees in sanitary engineering, mechanical engineering, chemical engineering, or other appropriate technical branches. A fair number of the industrial hygiene engineers of this country have received such training, although many have obtained their industrial hygiene engineering knowledge by experience in the field.

Health hazards of interest to the industrial health engineer are exposure to such conditions as excessive concentrations of dusts, fumes, mists, gases, and vapors; exposure to high, low, or rapidly changing temperatures; exposure to very high humidity; exposure to harmful amounts of radiant energy, such as infrared, ultraviolet, and roentgen rays, and radium emanation; exposure to noise; inadequate illumination; unnecessary fatigue; and other conditions which adversely affect the health, morale, and efficiency of the workers.

Because industrial hygiene is a relatively new field with only a small number of specialized personnel, most of the control equipment installed in the past and even today is "thrown in" by tinsmiths or sheet-metal engineers or is designed by plant engineers or consulting engineering firms who do not have the benefit of much of the data and information on proper design which is available to the industrial hygiene engineer. Much has been written on the subject of this book, but it is scattered throughout a large variety of publications and as such is not readily available to plant engineers. Furthermore, many of the reported investigations are so theoretical, so involved, so specific, or so contradictory that they are of little use to most plant engineers, who do not have the time required to make a study of the reports in order to apply the principles expounded to their immediate design problem. As a result, a much-too-large percentage of the control installations (particularly local exhaust and ventilating systems) which have been made in the past and are being made today are wholly unsatisfactory. It is for this reason that this book has been written—to make available to plant engineers, to construction and consulting engineering firms, and to inexperienced industrial hygiene engineers in condensed, practical, and useful fashion a summary of the information and data needed to determine what control measures should be employed and how control equipment should be designed so that when installed it has a fair chance of doing a satisfactory job.

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CHAPTER I

INDUSTRIAL ATMOSPHERIC CONTAMINANTS AND THEIR INDUSTRIAL HYGIENE SIGNIFICANCE

Wherever materials or substances are being processed or handled, except in air-tight systems or closed systems under negative pressure, some of the materials or substances or by-products thereof escape into the atmosphere either directly or by indirect routes. As a result, many occupations have injurious effects on the physical condition of those engaged in them. The occupation is now recognized as of major importance as a factor in causing disability and even death. This is reflected in the frequent revisions of compensation laws to include an increasing number of occupational diseases. The legal phases of industrial hygiene, therefore, are becoming of increasing importance and are focusing attention on the importance of the prevention of occupational diseases by proper industrial health engineering.

Industrial atmospheric contaminants are responsible for many occupational illnesses. These contaminants may be in the gaseous, liquid, or solid state, or in combinations of these. While this classification of industrial atmospheric contaminants is sufficiently definitive for most purposes, it is advantageous to have a finer breakdown for industrial hygiene purposes.

ATMOSPHERIC CONTAMINANTS

Gibbs[1] suggested the term "aerosol" for all contaminated atmospheres with a subdivision of industrial aerosols as dusts, clouds, and smokes on the basis of the degree of dispersion of the particles. This classification was not generally accepted by industrial hygiene workers in this country. Out of the evolution of industrial hygiene which took place in the era between the first and second world wars there arose a classification which has obtained common acceptance among industrial hygiene engineers in America, namely, dusts, fumes, mists, gases, and vapors. However, there was little mutual agreement

as to the exact content and boundary of each type of contaminant until the American Standards Association issued their preliminary edition of Code Z9 "Fundamentals Relating to the Design and Operation of Exhaust Systems" in 1936 which contained definitions of these five types of contaminants. Even as late as 1945 the *Heating, Ventilating, and Air Conditioning Guide* published annually by the American Society of Heating and Ventilating Engineers contained definitions of dusts, fumes, and gases which were not in agreement with those in the ASA code.

The ASA definitions of dusts, fumes, mists, gases, and vapors are as follows:

Dusts: Solid particles generated by handling, crushing, grinding, rapid impact, detonation and decrepitation of organic or inorganic materials such as rock, ore, metal, coal, wood, grain, etc. Dusts do not tend to flocculate except under electrostatic forces; they do not diffuse in air but settle under the influence of gravity.

Fumes: Solid particles generated by condensation from the gaseous state, generally after volatilization from molten metals, etc., and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce.

Mists: Suspended liquid droplets generated by condensation from the gaseous to the liquid state or by breaking up a liquid into a dispersed state, such as by splashing, foaming, and atomizing.

Gases: Normally formless fluids which occupy the space of enclosure and which can be changed to the liquid or solid state only by the combined effect of increased pressure and decreased temperature. Gases diffuse.

Vapors: The gaseous form of substances which are normally in the solid or liquid state and which can be changed to these states either by increasing the pressure or decreasing the temperature alone. Vapors diffuse.

For the purposes of engineering control of industrial atmospheric contaminants the foregoing breakdown is satisfactory since the various contaminants are divided according to those characteristics or properties which frequently dictate the control measures to be employed. Although of no great importance as regards occupational disease control, there seems to be need for a sixth group of contaminants, namely, smokes. No definition of smoke as specific as those for the other contaminant groups appears to be available, but it might be defined with sufficient exactness for the purpose of this book as follows:

Smoke: Carbon or soot particles less than 0.1 micron in size which result from the incomplete combustion of carbonaceous materials such as coal, oil, tar, and tobacco.[2]

The foregoing classification of industrial atmospheric contaminants is satisfactory for most industrial health engineering purposes. However, conditions are sometimes encountered which necessitate a modified or supplementary division. Thus the U. S. Bureau of Mines [3,4] has found it necessary in connection with the official testing and approval of respiratory protective devices to divide dusts into "pneumoconiosis-producing and nuisance dusts" and "toxic dusts"; to divide mists into "spray-coating mists," "chromic acid mist," and "mists whose liquid vehicle does not produce harmful gases or vapors"; and to further subdivide gases on the basis of the filter required to adequately remove the contaminant from the air.

For purposes other than engineering control the various atmospheric contaminants are sometimes classified differently. Dublin and Vane [5] group them all under three headings—dust, radiant energy, and poisons (including poisonous dusts)—largely on the basis of their physiological reactions. The dusts are further divided into organic dust, inorganic dust containing free silica, inorganic dust (except asbestos) containing no free silica, and asbestos. Poisons are subdivided into 128 separate materials, many of which are groups that might be further subdivided. Sayers [6] subdivided dusts into two groups, organic and inorganic. Drinker [7] classified all solid air-borne contaminants into four groups on the basis of the physiological reaction produced when inhaled: (1) those producing pneumoconioses, (2) those producing toxic reactions (poisoning), (3) those producing metal fume fever, and (4) those producing allergic reactions. It is therefore apparent that no rigid classification of atmospheric contaminants is suitable for all purposes. For engineering control, however, the classification dusts, fumes, smokes, mists, gases, and vapors is generally satisfactory.

INDUSTRIAL HYGIENE SIGNIFICANCE

Most atmospheric contaminants are toxic to a greater or lesser extent. When inhaled or absorbed regularly over a long period of time, some substances, such as benzol, cadmium, carbon tetrachloride, chlorine, and lead, are harmful even in low concentrations (see table 1). Others, such as calcium carbonate, carbon dioxide, fly ash, gasoline, methane, and sawdust, are relatively harmless in low concentrations. Acute poisoning may result after short exposure to unusually high concentrations of many air-borne materials. For most industrial atmospheric contaminants the most important mode

of entry to the body is via the respiratory tract, although most poisons may gain access to the body through the mouth, and a few, such as aniline, hydrocyanic acid gas, lead tetraethyl, and TNT, are absorbed through the skin in amounts sufficient to cause poisoning. As a rule, however, skin absorption is of secondary importance to inhalation, and it is automatically controlled if the atmospheric concentration is kept low enough to be safe for inhalation, except in those instances where there is direct body contact with the bulk material.

Fortunately the average human body can stand a certain amount of all materials however toxic they may be, the amount varying a great deal for different substances (see table 1) and even from person to person. If such were not the case, engineering control would be inestimably more difficult, if not impossible, in many instances. Laboratory research, field studies, and field and industrial experience have produced sufficient knowledge regarding the toxicology of many chemicals to permit maximum safe concentration limits to be established for many substances or types of substances encountered in the industrial atmosphere. These limits are called maximum allowable concentrations and represent the amount of a substance to which the average worker may be exposed for 8 hours daily without significant harmful effects. Because of the variation from individual to individual, some few workers can stand considerably higher concentrations, while others become ill even when exposed to concentrations below the maximum allowable values. Careful pre-employment examinations with selective placement of the employees will generally prevent poisoning of the unusually susceptible individual. Also routine periodic physical examination of all workers exposed to toxic materials serves two very important purposes. It indicates which workers, if any, are showing signs of poisoning before the degree thereof has advanced to an irreparable or harmful state. It serves also to point out to the engineer where the exposures are excessive and better control measures are needed. Workers showing signs of early poisoning should be removed from the exposure, treated on the job if such procedure is indicated, or provided with suitable personal protective equipment until they have returned to normal and/or until the exposure has been brought under control.

It will be noted from table 1 that the units of measure are not uniform for different air-borne materials. In general, the concentration of gaseous contaminants is expressed as parts of contaminant

TABLE 1

LIST OF MAXIMUM ALLOWABLE CONCENTRATIONS [a]

Substance	*Maximum Allowable Concentrations* ppm [b]	mg/m³ [c]	*See Notes* (p. 8)
Acetaldehyde	200	360 *	*d*
Acetic acid	10	25 *	*d*
Acetone	500	1,190 *	*d, e*
Acetylene tetrachloride (tetrachloroethane)	10	69 *	*f*
Acrolein	1	2.3 *	*f*
Acrylonitrile	20	44 *	*d, f*
Ammonia	100	69 *	*d, f*
Amyl acetate	400	2,120 *	*f*
Amyl alcohol	200	720 *	*g*
Aniline	5	19 *	*d, f*
Arsenic		0.15	*h*
Arsine	1	3.2 *	*d, f*
Asbestos	5 mppcf		*i*
Barium peroxide (as barium)		0.5	*d, f*
Benzene (benzol)	100	320 *	*h*
Benzine (gasoline)	1,000		*f*
Bromine	1	6.5 *	*d*
Butadiene	5,000	11,000 *	*d*
Butanone (methyl ethyl ketone)	200	580 *	*d*
Butyl acetate	400	1,670 *	*f*
Butyl alcohol (butanol)	200	605 *	*f*
Butyl cellosolve	200	965 *	*d*
Cadmium		0.1	*h*
Carbon dioxide	5,000	9,000 *	*d, f*
Carbon disulfide	20	62 *	*h*
Carbon monoxide	100	115 *	*h*
Carbon tetrachloride	100	630 *	*d, f*
Cellosolve	200	740 *	*d*
Cellosolve acetate	100	540 *	*d*
Chlorine	1	2.9 *	*e, g*
Chlorodiphenyl		1.0	*d*
Chloroform	100	490 *	*d*
Chloroprene (chlorobutadiene)	25	91 *	*d*
Chromic acid		0.1	*h*
Cyclohexane	400	1,380 *	*d*
Cyclohexanol	100	410 *	*d*
Cyclohexanone	100	400 *	*d*
Dichlorobenzene	75	450 *	*d, f*
Dichlorodifluoromethane ("Freon 12")	100,000		*d*

* All concentrations given in mg/m³ which are marked with the asterisk were computed from the maximum allowable concentration in terms of ppm.

TABLE 1 (*Continued*)

LIST OF MAXIMUM ALLOWABLE CONCENTRATIONS [a]

Substance	*Maximum Allowable Concentrations* ppm [b]	mg/m³ [c]	*See Notes* (p. 8)
Dichloroethylene	100	395 *	*d, e*
Dichloroethyl ether	15	88 *	*d*
Dichloromethane	500	1,740 *	*d*
Dichloromonofluoromethane ("Freon 21")	5,000		*d*
Dichlorotetrafluoroethane ("Freon 114")	10,000		*d*
Difluoromonochloromethane ("Freon 22")	20,000		*d*
Dimethylaniline (xylidine)	5	25 *	*d, f*
Dimethylsulfate	1	5.2 *	*d*
Dinitrotoluene		1.5	*f*
Dioxane	500	1,800 *	*d*
Ethyl acetate	400	1,440 *	*d, e*
Ethyl alcohol (ethanol)	1,000	1,880 *	*d, e*
Ethyl benzene	200	870 *	*d*
Ethyl bromide	400	1,790 *	*d*
Ethyl chloride	5,000	13,200 *	*d*
Ethylene dichloride	100	405 *	*d, f*
Ethylene oxide	100	180 *	*d*
Ethyl ether	500	1,515 *	*d*
Ethyl formate	200		*d*
Ethylidine chloride	100	405 *	*d*
Ethyl silicate	100	850 *	*d*
Fluoride dusts, smokes		1.0	*d*
Formaldehyde	10	12 *	*h*
Gasoline	1,000		*f*
Heptane	500	2,040 *	*d*
Hexane	1,000	3,520 *	*d*
Hexanone (methyl butyl ketone)	200	820 *	*d*
Hexone	200		*d*
Hydrochloric acid	10	15 *	*d, f*
Hydrogen cyanide	20	22 *	*d, f*
Hydrogen fluoride	3	2.5 *	*d, f*
Hydrogen selenide	0.1	0.3 *	*d*
Hydrogen sulfide	20	28 *	*h*
Iodine	0.1	1.0 *	*d*
Iron oxide		30	*g*
Isophorone	25	140 *	*d*
Lead		0.15	*h*
Magnesium oxide		15	
Manganese		6	*h*

* All concentrations given in mg/m³ which are marked with the asterisk were computed from the maximum allowable concentration in terms of ppm.

TABLE 1 (*Continued*)

LIST OF MAXIMUM ALLOWABLE CONCENTRATIONS [a]

Substance	Maximum Allowable Concentrations ppm [b]	mg/m^3 [c]	See Notes (p. 8)
Mercury		0.1	*h*
Methyl acetate	400	1,210 *	*e*
Methyl alcohol (methanol)	200	260 *	*h*
Methyl bromide	20	78 *	*d*
Methyl cellosolve	100	310 *	*d*
Methyl cellosolve acetate	100	485 *	*d*
Methyl chloride	200	460 *	*d*
Methyl cyclohexane	1,000	4,010 *	*d*
Methyl cyclohexanol	100	465 *	*d*
Methyl cyclohexanone	100	460 *	*d*
Methyl formate	400		*d*
Monochlorobenzene	75	345 *	*d, f*
Monofluorotrichloromethane ("Freon 11")	10,000		*d*
Mononitrotoluene	5	28 *	*f*
Naphtha (coal tar)	200		
Naphtha (petroleum)	1,000	4,500 *	*e*
Nitrobenzene	5	25 *	*f*
Nitroethane	200	615 *	*d*
Nitrogen oxides	25		*h*
Nitroglycerin	0.5	4.6 *	*d, f*
Nitromethane	200	500 *	*d*
Nuisance dusts	50 mppcf		*i*
Octane	500	2,330 *	*d*
Ozone	1	2.0 *	*d*
Pentachloronaphthalene		0.5	*d*
Pentane	5,000		*d*
Pentanone (methyl propanone)	400	1,175 *	*d*
Perchlorethylene	200	1,360 *	*d, f*
Phosgene	1	4.0 *	*d, f*
Phosphine	1		*d, f*
Phosphorus trichloride	0.5	2.8 *	*d*
Propyl acetate	400	1,670 *	*e*
Propyl alcohol	400	980 *	*d*
Propyl ether	500	2,090 *	*d*
Quartz (free silica)	5 mppcf		*f, i*
Radon (radium emanation)	10^{-11} Curie/liter		*j*
Silica (free)	5 mppcf		*f, i*
Solvesso	200	1,020 *	

* All concentrations given in mg/m^3 which are marked with the asterisk were computed from the maximum allowable concentration in terms of ppm.

TABLE 1 (*Continued*)

LIST OF MAXIMUM ALLOWABLE CONCENTRATIONS [a]

Substance	*Maximum Allowable Concentrations* ppm [b]	mg/m³ [c]	*See Notes* (p. 8)
Stibine	10		*d*
Stoddard solvent	1,000	5,320 *	*e*
Styrene monomer	400	1,700 *	*h*
Sulfur chloride	1	5.5 *	*d*
Sulfur dioxide	10	26 *	*d, f*
Sulfuric acid		5	*d*
Tellurium		0.01	*d*
Tetrachloroethylene	200	1,360 *	*d, f*
Tetryl		1.5	*f*
Toluene (toluol)	200	750 *	*h*
Toluidine	5	22 *	*d*
Trichloroethylene	200	1,070 *	*d, f*
Trichloronaphthalene		5	*d*
Trinitrotoluene (TNT)		1.5	*f*
Turpentine	200	1,110 *	*f*
Vinyl chloride	1,000	2,560 *	*d*
X ray	0.1 Roentgen		*h*
Xylene (xylol)	200	870 *	*h*
Zinc oxide		15	*d, f*

* All concentrations given in mg/m^3 which are marked with the asterisk were computed from the maximum allowable concentration in terms of ppm.

NOTES

a. The maximum allowable concentration is that atmospheric concentration of substance to which the average worker can be subjected 8 hours daily without causing illness.

b. ppm = parts of substance per million parts of air by volume.

c. mg/m^3 = milligrams of substance per cubic meter of air.

d. Values selected from an article entitled "Maximum Allowable Concentrations of Industrial Atmospheric Contaminants" by W. A. Cook which appeared in the November, 1945, issue of *Industrial Medicine.*

e. Values taken from an article entitled "The Role of the Ventilating Engineer in Industrial Hygiene" by A. D. Brandt which appeared in the March, 1946, issue of *Heating and Ventilating.*

f. Values taken from Chapter 11 of the *Manual of Industrial Hygiene* (see reference 47).

g. Values taken from publications of the New York State Department of Labor.

h. Values taken from Maximum Allowable Concentration Codes issued by the American Standards Association.

i. mppcf = millions of particles per cubic foot of air. Fibrosis-producing dusts and nuisance dusts are quantitated by direct count, rather than on a weight basis, for reasons given in Chapters I and II.

j. Value taken from *National Bureau of Standards Handbooks* H-24 and H-27.

per million parts of air by volume (ppm), and the concentration of particulate contaminants (dusts, fumes, and mists) is expressed in milligrams of the contaminant per cubic meter of air (mg/m^3). The two important exceptions to this general rule are mercury vapor which is expressed on the weight basis and fibrosis-producing and nuisance dusts which are given in terms of millions of particles per cubic foot of air (mppcf). The reason for number concentrations rather than weight concentration is explained in Chapter II. Until recently the atmospheric concentration of carbon monoxide was expressed in parts per ten thousand.

While these units of measurement are satisfactory for most purposes, there are occasions when it is necessary to convert ppm to mg/m^3, particularly when trying to obtain a clear picture of the relative toxicity of a gaseous and particulate contaminant. This conversion can readily be made if it is borne in mind that one molecular weight of a substance when in the gaseous state will occupy 24.4 liters at room temperature (25° C) and 760 mm barometric pressure. For convenience in making these calculations, conversion units for different molecular weights are given in Table A of the Appendix at the rear of the book. The maximum allowable concentrations by weight have been computed for most gaseous contaminants shown in table 1 and are marked with an asterisk. This has been done to assist the reader in forming a mental picture of the comparative toxicity of the different substances. Reference to the table will indicate at a glance that, as a general rule, the poisons which exist in the atmosphere as dusts and fumes are much more toxic than those which are present in the gaseous state. The important exception is mercury, which, as stated earlier, is the only gaseous contaminant commonly expressed on a weight basis. If the maximum allowable concentration values are not expressed on the same basis it is impossible to obtain an accurate impression of their relative toxicity as evidenced, for example, by acrolein, arsine, and bromine.

It is common practice to give maximum allowable concentrations in definite values, usually round numbers. Only trouble will result, however, if these values are considered anything other than yardsticks. Very definitely they are not intended to indicate a degree of contamination which if exceeded even a little will result in much illness, and if the exposure is less no harm will result. There are too many variables involved from worker to worker, from day to day, and from operation to operation to assign any value to these limits

other than that of guideposts. For this reason the maximum allowable concentrations, whether on a volume or weight basis, are usually given in round numbers and in approximately 100% steps. Thus most of the values (other than those marked with an asterisk) in table 1 are in the following units: 0.5, 1, 2, 5, 10, 20, 25, 50, 100, 200, 400, 500, 1000, etc.

Even though these values are intended only as measuring sticks, the author favors ranges rather than specific values. None of the individual values are so definite that a range will not serve satisfactorily, and with ranges rather than specific values the engineer is frequently in a much better position to justify and sell his recommendations. In addition much of the discord now in evidence on the maximum allowable concentrations of several substances would be eliminated since the range would include both values in question such as 50–100 ppm for carbon tetrachloride and benzol.

Physiological Action. While a thorough knowledge of the physiological action of different types of industrial atmospheric contaminants comes within the scope of the toxicologist and the industrial hygiene physician, not the engineer, the better acquainted the engineer is with this phase of industrial hygiene, the better equipped he will be to do a good job. Consequently, a concise summary of industrial air-borne materials by their mode of action is given herein. More detailed information may be found in a number of books, pamphlets, and articles on this subject.[5, 6, 7, 8, 9, 10, 11, 12, 13]

Although it is difficult to separate the types of industrial atmospheric contaminants into distinct groups from the viewpoint of physiological action, for the purpose of this summary it is advisable to consider them all in two broad groups and then to subdivide these groups. Thus all nonliving industrial air-borne materials may be divided into particulate matter (dusts, fumes, mists, and smokes) and gaseous substances (gases and vapors). Particulate matter may be divided into six general, although not-too-distinct groups, namely, irritants, toxic dusts, fibrosis-producing dusts, inert dusts, allergy-producing dusts, and fever-producing substances.

Irritating dusts are those which usually produce only local reactions. Examples are caustics, lime, picric acid, ammonium picrate, soap powder, methyl violet, cereal dusts, and paraphenylene diamine. Toxic dusts are differentiated from irritant dusts in that they produce remote (usually systemic poisoning) rather than local effects. They are commonly absorbed into the blood stream through the

lungs, digestive tract, or skin and harm particular organs. A dust may be both irritating and toxic. Examples of toxic dusts are lead, arsenic, mercury, zinc, manganese, cadmium, phosphorus, and certain dyestuff intermediates. Fibrosis-producing dusts (free silica and asbestos) result in the production of fibrous tissue in the lungs (silicosis and asbestosis) which in itself may not be seriously incapacitating but predisposes the worker to tuberculosis. Inert dusts are the materials such as coal, Alundum, marble, rouge, and emery which do not produce fibrous tissue in the lungs or cause systemic poisoning when absorbed. An inert dust may also be irritating. Allergy-producing dusts usually affect only certain people who are particularly susceptible. Examples are pollen, certain kinds of wood dust and cotton dust, fur, feathers, horsehair, and wool. Allergic phenomena are most frequently manifested through skin reactions but may cause acute reactions elsewhere in the body, such as hay fever or asthma. Fever-producing substances are usually fumes such as magnesium and zinc oxide which produce metal-fume fever when inhaled.

The other major group, gaseous substances, may be subdivided into four general even though not-distinct groups, namely, asphyxiants, irritants, inorganic and organometallic gases, and volatile drugs and druglike substances. The asphyxiants do no direct damage to the lungs but induce asphyxiation by interfering with the supply or utilization of oxygen. There are two types of asphyxiants: simple asphyxiants, such as methane, nitrogen, helium, and hydrogen, which act only in high concentration by producing an oxygen-deficient atmosphere; and chemical asphyxiants (carbon monoxide and cyanide compounds), which act even in low concentrations by interfering with the utilization of the oxygen by the body.

Irritants are those gases and vapors which might be considered corrosive and might cause inflammation of the skin, eyes, or respiratory tract. Examples are ammonia; hydrochloric, sulfuric, and hydrofluoric acid gases; sulfur dioxide; chlorine; acrolein; nitrogen oxides; ozone; and certain hydrocarbons. Some gases, such as acrolein, hydrogen sulfide, and some of the hydrocarbons, are both irritating and general poisons.

The inorganic and organometallic gases are those which contain mercury, phosphorus, lead, arsenic, etc., such as diethylarsine, tetraethyl lead, nickel carbonyl, hydrogen sulfide, hydrogen arsenide, mercury, phosphorus, and cacodyl.

The last group (volatile drugs and druglike substances) is a very large group which may be subdivided into five subgroups. (1) Anesthetic gases, such as ketones, aldehydes, ethers, nitrous oxide, and fatty hydrocarbons, which produce no serious aftereffects. (2) Anesthetic gases which cause organic changes mainly in the visceral organs. These are the halogen derivatives of the fatty hydrocarbons, such as trichloroethylene, perchloroethylene, methyl chloride, carbon tetrachloride, dichloroethylene, and acetylene tetrachloride. (3) Anesthetic gases which cause organic changes mainly in the hematopoietic system. These are the hydrocarbons of the aromatic series (coal-tar products), such as benzol, toluol, xylol, phenol, creosote, and "solvent naphtha." (4) Anesthetic gases which produce organic changes primarily in the nervous system. These substances are the alcohols and sulfur derivatives of fatty hydrocarbons. Examples are methyl, amyl, ethyl, propyl, and butyl alcohol, carbon disulfide, and thiophene. (5) Organic nitrogen compounds, such as aniline, nitrobenzene, toluidine, and dimethylaniline, which affect the blood and circulation.

Industrial Health Hazards by Occupation. Occupational-disease hazards exist at many operations and in many industries. Their number and variety are much greater than is realized by management, industrial physicians, safety engineers, plant engineers, and even many of the industrial hygiene profession. Tables 2 and 3 contain in useful form a list of industrial health hazards by industry, process, and operation. These tables were prepared from the data in reference 5 to serve as a handy guide in determining what to look for at a large number of occupations selected from a variety of industries. The occupational disease hazards are classified in table 2 and are assigned index numbers which are used in table 3 to indicate the hazards which may be encountered at each occupation given in this table. Hence, to determine what hazards to look for at a given occupation, the occupation is located in table 3 and the index numbers are noted for reference to table 2 from which the hazards are obtained conveniently.

TABLE 2

Occupational Health Hazards

INDEX NUMBER	HAZARD
	Abnormalities of Air Pressure
1	Compressed air (increased atmospheric pressure)
2	Rarefied air; altitude (decreased atmospheric pressure)
	Abnormalities of Temperature and Humidity
3	Heat
4	Sudden variations of temperature
5	*Dampness*
6	*Defective Illumination*
	Dust
7	Asbestos
8	Inorganic dust containing free silica
9	Inorganic dust (except asbestos) containing no free silica
10	Organic dust
	Infections
11	Anthrax
12	Fungus infections
13	Septic infections
14	Undulant fever (brucellosis)
	Radiant Energy
15	Ultraviolet and infrared rays
16	X rays, radium, and other radioactive substances
17	*Repeated Motion, Pressure, Shock, etc.*
	Poisons
18	Acetaldehyde
19	Acetanilide
20	Acetone
21	Acridine
22	Acrolein
23	Aluminum
24	Aluminum oxide
25	Ammonia
26	Amyl acetate
27	Amyl alcohol
28	Aniline and other amido compounds of benzol and its homologues
29	Antimony and its compounds
30	Arsenic and its compounds (except arsine)
31	Arsine (arseniuretted hydrogen)
32	Barium
33	Benzine (naphtha, gasoline)
34	Benzol (benzene) and its homologues (toluol and xylol)
35	Beryllium
36	Brass

TABLE 2 (*Continued*)

OCCUPATIONAL HEALTH HAZARDS

INDEX NUMBER	HAZARD
	Poisons (Continued)
37	Bromine
38	Butanone (methyl ethyl ketone)
39	Butyl acetate
40	Butyl alcohol
41	Cadmium
42	Calcium cyanamide
43	Carbon dioxide
44	Carbon disulfide
45	Carbon monoxide
46	Carbon tetrachloride
47	Cellosolve (monoethyl ether of ethylene glycol)
48	Chloride of lime
49	Chlorinated diphenyls
50	Chlorinated hydrocarbons
51	Chlorinated naphthalenes
52	Chlorine
53	Chlorodinitrobenzol
54	Chloronitrobenzol
55	Chloroprene
56	Chromium compounds
57	Cobalt
58	Copper
59	Cresol (cresylic acid)
60	Cyanogen compounds
61	Dichloroethylene
62	Dichloroethyl ether
63	Dimethyl sulfate
64	Dinitrobenzol
65	Dinitrophenol
66	Dioxan (diethylene dioxide)
67	Ethyl benzene
68	Ethyl bromide and ethyl chloride
69	Ethylene dibromide
70	Ethylene dichloride (dichloroethane)
71	Ethylene oxide
72	Ethyl silicates: tetraethyl-ortho-silicate, tetramethyl-ortho-silicate
73	Fluorine and its compounds
74	Formaldehyde
75	Formic acid
76	Furfural
77	Gasoline

TABLE 2 (*Continued*)

OCCUPATIONAL HEALTH HAZARDS

INDEX NUMBER	HAZARD
	Poisons (Continued)
78	Hexanone (methyl butyl ketone)
79	Hexone (methyl isobutyl ketone)
80	Hydrochloric acid
81	Hydrocyanic acid
82	Hydrofluoric acid
83	Hydrogen sulfide (sulfuretted hydrogen)
84	Iron carbonyl
85	Iron oxide
86	Lead and its compounds
87	Lead arsenate
88	Magnesium
89	Magnesium oxide
90	Manganese
91	Mercury and its compounds
92	Methanol (methyl alcohol)
93	Methyl bromide
94	Methyl cellosolve (ethylene glycol monoethyl ether)
95	Methyl chloride
96	Methylene chloride (dichloromethane)
97	Methyl formate
98	Naphtha
99	Naphthols
100	Naphthylamines
101	Nickel
102	Nickel carbonyl
103	Nicotine
104	Nitraniline
105	Nitrobenzol and other nitro compounds of benzol and its homologues
106	Nitrogen oxides (nitrous fumes) and nitric acid
107	Nitroglycerin
108	Nitronaphthalene
109	Oxalic acid
110	Ozone
111	Pentanone (methyl propyl ketone)
112	Petroleum
113	Phenol
114	Phenyl hydrazine
115	Phosgene
116	Phosphine (phosphoretted hydrogen)
117	Phosphorus
118	Picric acid (trinitrophenol)

TABLE 2 (*Continued*)

OCCUPATIONAL HEALTH HAZARDS

INDEX NUMBER	HAZARD
	Poisons (Continued)
119	Potassium hydroxide
120	Pyridine
121	Radium and radon
122	Selenium compounds
123	Silver
124	Sodium hydroxide
125	Sulfur chloride
126	Sulfur dioxide
127	Sulfuric acid
128	Tar and pitch
129	Tellurium compounds
130	Tetrachloroethane (acetylene tetrachloride)
131	Tetrachloroethylene (perchloroethylene)
132	Tetraethyl lead
133	Thallium
134	Thorium
135	Tin
136	Titanium oxide
137	Toluol (toluene)
138	Trichloroethylene
139	Trinitrophenol
140	Trinitrotoluol (trinitrotoluene, TNT)
141	Triorthocresyl phosphate
142	Turpentine
143	Uranium
144	Vanadium
145	Vinyl chloride
146	Xylol (xylene)
147	Zinc
148	Zinc oxide

TABLE 3

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Abrasives workers, 3, 8, 9, 10
Acetaldehyde workers, 18, 91
Acetanilide workers, 28
Acetic acid makers, 80, 91
Acetone workers, 20, 91
Acetylene workers, 9, 20, 25, 31, 44, 45, 48, 56, 116; *see also* Carbide makers *and* Welders
Acid dippers, 5, 31, 60, 80, 106, 127
Acid finishers (glass), 80, 86, 127
Acid makers, *see particular acid*
Acridine workers, 21
Acrolein workers, 22
Actors, 86
Agricultural workers, *see* Farmers
Air-hammer operators, 17
Airplane-dope makers, 20, 26, 34, 46, 75, 94, 130
Airplane-hangar employees, 33, 34, 46
Airplane pilots, 2, 45
Airplane pilots—crop dusting, 2, 30, 45, 86
Airplane-wing varnishers, *see* Varnishers
Alcohol-distillery workers, 26, 27, 34, 75, 91, 92
Aldehyde pumpmen, 18, 92
Alkali salt makers, 5, 43, 52, 80, 83, 126
Alloy makers, 3, 35, 45, 57, 88, 89, 101, 122, 144
Aluminum extractors, 82, 90
Alum workers, 127
Amalgam makers, 91
Amber workers, 86
Ammonia workers, 25, 42, 45
Ammonium salt makers, 3, 25, 44, 60, 80, 127
Ammonium sulfate makers, 127
Amyl acetate workers, 26, 27
Amyl alcohol workers, 27
Amyl nitrite makers, 27
Aniline dye makers, *see* Dye makers
Aniline workers, 28, 31, 34, 56, 80, 105, 106
Animal-hair dressers, *see* Hair workers
Animal handlers, 11, 12, 13
Annealers, 3, 25
Antifreeze makers, 92
Antimony extractors (refiners), 3, 29
Antimony fluoride extractors, 82
Antipyrine makers, 114
Arsenic roasters, 3, 30
Art-glass workers, 26, 33, 82, 86, 92, 142
Artificial-amber makers, 74
Artificial-flower makers, 17, 30, 56, 86, 91, 92
Artificial-gem makers, 133
Artificial-ice makers, 4, 5, 25, 126
Artificial-leather workers, 3, 20, 26, 28, 30, 34, 38, 40, 92, 106, 127
Artificial-manure makers, *see* Fertilizer makers
Artificial-pearl makers, 20, 26, 86, 106, 130
Artificial-rubber makers, *see* Rubber (synthetic) makers
Artificial-silk makers, *see* Rayon
Artificial-stone makers, 128
Asbestos miners, 7; *see also* Miners
Asbestos-products workers, 3, 7, 34, 74, 128
Ashmen, 9, 10
Asphalt workers, 3, 128
Automobile mechanics, *see* Garage workers
Automobile painters, 5, 34, 92; *see also* Painters
Automobile-radiator cleaners, 109
Aviation personnel (flying), 2; *see also* Airplane pilots
Aviators, *see* Airplane pilots

Babbitters, 29, 86
Babbitt-metal workers, 29, 86
Bacteriologists, 11
Bakers, 4, 10, 15, 43, 45
Baking-powder makers, 43
Balloon (hydrogen) workers, 31
Balloon inflators, 45
Barbers, 11, 12, 13, 14, 17
Barium carbonate makers, 32, 83
Bar-mill workers (iron and steel), 3
Barometer makers, 91

TABLE 3 (*Continued*)

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Basic-slag (artificial manure) workers, 9
Batch makers (glass works), *see* Glass mixers
Batch makers (rubber works), *see* Compounders (rubber)
Baters (tannery), 11
Bathhouse attendants, 11, 12, 13, 14
Battery (dry) makers, 9, 10, 26, 34, 56, 80, 86, 90, 91, 128
Battery (storage) makers, *see* Storage battery makers
Beamers (textiles), 10
Beamhouse workers (tannery), 5, 11
Beatermen (paper and pulp), 5, 52
Beauty-parlor operatives, 34
Bed rubbers (stone), 8, 9
Bench molders, *see* Molders (foundry)
Benzene workers, *see* Benzol workers
Benzine workers, 33
Benzol purifiers, 34, 127
Benzol-stillmen, 3, 34
Benzol workers, 34
Beryllium alloy workers, 35
Beryllium extractors, 82
Bessemer-converter workers (iron and steel), 3, 45
Beta-still operators (beta naphthol), 3, 127
Bevelers, 9
Bicyclists, 17
Billet-mill workers (iron and steel), 3
Bisque-kiln workers, 3, 8, 9, 45
Blacksmiths, 3, 15, 17, 43, 45, 60, 86
Blanket makers, 11
Blasters, 8, 9, 45, 83, 106
Blast-furnace workers, 3, 43, 45, 60, 83, 116, 126
Bleachers, 3, 4, 48, 52, 56, 80, 82, 106, 109, 110, 115, 119, 124, 126
Bleachery driers, 3
Bleaching-powder makers, 31, 48, 52, 90
Blenders (motor fuel), *see* Gasoline blenders
Blockers (felt hats), 3, 45
Blooders (tannery), 86
Blooming-mill workers (iron and steel), 3
Blowers (felt hats), 10, 91
Blowers (glass manufacturing), *see* Glass blowers
Blowers-out (zinc smelting), 3, 24, 147, 148
Blueprint makers, 56
Blueprint paper makers, 28, 109
Bluers (revolvers), 3
Boiler cleaners and washers, 5, 45
Boiler-room workers, 3, 43, 45
Boneblack makers, 25, 117
Bone renderers, extractors, etc., 10, 11, 22, 60, 126
Bookbinders, 22, 26, 30, 86, 92, 109
Bottle-cap makers, 86
Bottlers (mineral waters), 43, 83
Brake-lining workers, 7, 34
Brass founders, 3, 24, 29, 30, 43, 45, 58, 86, 116, 126, 127, 147, 148
Brass polishers, 86, 147; *see also* Polishers and cleaners (metal)
Braziers, 3, 15, 24, 86, 147, 148
Brewers, 3, 4, 5, 12, 27, 43, 45, 74, 82, 113, 127
Brick burners, 3, 43, 45, 86
Bricklayers, 9
Brick makers, 3, 5, 8, 9, 82, 86, 88, 90, 126
Briquet makers, 30, 128
Bromine makers, 28, 37, 52
Bronze-powder makers, 20, 24, 147, 148
Bronzers, 9, 24, 25, 26, 30, 31, 33, 34, 60, 80, 83, 86, 90, 91, 92, 147, 148
Broom makers, 10, 11, 52, 74, 126
Browners (gun barrels), 60, 86, 91, 112
Brushers (felt hats), 10, 91
Brush makers, 10, 11, 74, 86, 92, 128
Buffers, 6, 9, 10
Buffers (rubber), 26, 33, 86
Bulb (mercury) makers, 91
Buoy makers, 116
Burners (enameling), 3, 86
Burnishers (metals), 6, 29, 33, 46, 127 138
Burrers (needles), 8, 9
Burr filers, 9

TABLE 3 (*Continued*)

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Butchers, 4, 11, 13, 14
Button makers, 9, 10, 20, 48, 74
Butyl acetate makers, 40
Butyl alcohol makers, 40
Butyl cellosolve makers, 71

Cable makers, 86
Cable splicers, 5, 45, 83, 86, 142
Cadmium alloy makers, 41
Cadmium and cadmium-compound makers, 31, 41
Cadmium platers, 41; *see also* Electroplaters
Cadmium-vapor-lamp makers, 41
Caisson workers, 1, 4, 5, 6, 43, 45, 83
Calcium carbide makers, *see* Carbide makers
Calcium cyanamide makers, 3, 9, 42
Calenderers (rubber), 4, 9
Calico printers, *see* Textile printers
Camphor makers, 26, 28, 80, 142
Candle makers, 22, 28, 30, 56, 127
Candy makers, 3, 4
Canners, 3, 4, 5, 13, 30, 43, 86
Can sealers, 34
Cap loaders, 91
Cappers (window glass), 3
Carbanilide makers, 44
Carbide makers, 3, 9, 10, 25, 45
Carbolic acid makers, 34, 113, 126, 127
Carbonated-water makers, 43
Carbon black workers, 3, 10
Carbon-brush makers, 9, 10
Carbon dioxide ice workers, 43
Carbon dioxide makers, 43
Carbon disulphide makers, 44, 83
Carbonic acid makers, 43
Carbonizers (shoddy), 10, 31, 80, 127
Carbon-paper makers, 10
Carbon printers (photography), 56
Carbon tetrachloride workers, 44, 46, 115, 125
Carders (asbestos), 7
Carders (textiles), 10
Card grinders (textiles), 9, 10
Carpenters, 17
Carpet cleaners, 10, 11
Carpet makers, 10, 11, 30
Carroters (felt hats), 30, 91, 106
Cartridge-cup washers, 5
Cartridge dippers, 80, 106, 127
Cartridge-felt and wad makers, 5
Cartridge makers, 86, 91
Cartridge-shot-shell-paraffin dippers, 4, 5
Case hardeners, 3, 60
Casters (metal), *see* Foundry *and also particular metal*
Casting cleaners (foundry), 8, 9; *see also* Acid dippers
Cast scrubbers (electroplaters), 33, 34
Catchers (iron and steel), 3
Cattle salesmen, 11, 14
Cellulose formate makers, 75
Cellulose makers, 5, 83, 124, 126, 127
Cellulose-products makers, *see* Rayon makers, Pyroxylin plastics workers, *and* Lacquer makers
Cementers (rubber), 33, 34, 40, 44, 46, 61, 92, 130, 138, 142
Cement (Portland) workers, 3, 8, 9, 30, 45, 122
Cement (rubber, plastic, etc.) mixers, 20, 25, 26, 33, 34, 44, 46, 66, 86, 120, 125, 128, 130
Ceramic workers, *see* Pottery workers
Chambermaids, 11, 12, 13
Chambermen (sulfuric acid), 126, 127
Charcoal burners, 43, 45
Charcoal workers, 10, 45
Charcoal workers (sugar refining), 3, 4
Chargers (furnace), 3, 9, 45; *see also particular metal*
Chargers (smelting and refining), 3, 9, 45; *see also particular metal*
Chasers (steel), 9
Chauffeurs, 4, 5, 17, 33, 45
Chemists (radium research), 16
Chimney masons, 45
Chimney sweepers, 9, 30, 45, 128
Chippers, 8, 9, 86
Chloride of lime makers, 48, 52
Chlorinated diphenyl makers, 49

TABLE 3 (*Continued*)

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Chlorinated naphthalene workers, 51
Chlorinated rubber makers, 46
Chlorine compound makers, 80
Chlorine makers, 52, 80, 90, 91
Chlorodiphenyl makers, 34
Chloroform makers, 20, 46, 48, 95
Chrome workers, 56
Chromiumplaters, 56; *see also* Electroplaters
Cigar makers, 10, 12, 86, 103
Clay and bisque makers (pottery), 4, 5, 8, 9
Clay-plug makers (pottery), 5, 9
Clay-products workers, *see* Pottery workers
Cleaners (metal), *see* Polishers and cleaners (metal)
Clerks, 6, 17
Clothes pressers, 43
Cloth preparers, 3, 5; *see also* Bleachers
Cloth singers, 45
Clutch-disc impregnators, 34
Coal carbonizers, 83
Coal miners, *see* Miners
Coal passers, 9, 10
Coal-tar workers, 3, 28, 34, 45, 59, 60, 113, 128; *see also* Coke-oven workers
Cobbers (asbestos), 7
Cobblers, 10, 11, 17, 34, 46
Coin makers, 101, 123
Coke-oven workers, 3, 25, 34, 45, 83, 126, 128; *see also* Coal-tar workers
Cold-storage-plant workers, *see* Refrigerating-plant workers
Collar (fused) makers, 20, 92, 94
Collodion makers, 106
Colored-paper workers, 30
Colorers (marble), 56
Colorers (white) of shoes, 86
Color makers, 3, 9, 25, 28, 29, 30, 33, 34, 37, 41, 52, 56, 57, 63, 86, 90, 91, 93, 95, 99, 122, 127, 130, 133
Comb makers, 10, 20
Compositors, 6, 9, 17, 28, 29, 33, 86, 142
Compounders (rubber), 9, 28, 29, 30, 33, 34, 56, 86
Compressed-air (caisson) workers, *see* Caisson workers
Compressed-air (pneumatic tool) workers, *see* Pneumatic-tool workers
Concentrating-mill workers, 5, 8, 9, 86, 90, 122; *see also* Oil flotation plant workers
Coners (felt hats), 10, 91
Confectioners, *see* Candy makers
Construction workers, 5, 8, 9
Cooks, 4, 11, 12, 13, 14, 15, 45
Copper founders, 30, 58
Copper miners, *see* Miners
Copper refiners and smelters, 3, 29, 30, 45, 58, 82, 86, 90, 122, 126, 129
Coppersmiths, 30, 58
Copper (strip) roller-mill workers, 22
Cordage-factory workers, 11, 128
Core makers, 3, 8, 9, 24, 45, 46, 85, 89, 147, 148
Cork workers, 10
Corn-products workers, 3, 4, 5
Cosmetic workers, 30, 91, 94, 105
Cotton-mill workers, 3, 5, 9, 10
Cottonseed-oil workers, 3
Cotton twisters, 10, 17
Cranemen (glass industry), 3
Cranemen (iron and steel), 3
Crayon (colored) makers, 56, 86
Creosoting-plant workers, 5, 128
Cresol soap makers, 59
Cresylic acid makers, 59
Crucible mixers, 9, 10
Crucible-steel-department employees, 3
Crushermen (clay and stone), 8, 9
Crushers (asbestos), 7
Cupola men (foundries), 3, 43, 45
Curers, vapor (rubber), *see* Vulcanizers
Curriers (tannery), 10, 11, 30, 33
Cut-glass workers, 9, 30, 86
Cutlery makers, 8, 9, 26, 86
Cutters (oxyacetylene and other gases), *see* Welders
Cyanamide makers, 3, 9, 42
Cyanide workers, 25, 60
Cyanogen makers, 60, 83, 91

TABLE 3 (*Continued*)

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Dairy workers, 11, 14
Damascening workers, 106
Dancers, 17
Dead-animal handlers, 11, 12, 13, 14
De-brassers, 108
Decorators (pottery), 30, 33, 34, 86, 91, 142
Degreasers, 33, 34, 44, 46, 51, 62, 66, 70, 96, 130, 131, 138
Denatured-alcohol workers, *see particular denaturant*
Dental workers, 86, 91
Dentists, 16, 91
Depilatory makers, 32, 133
Detinning workers, 52
Detonator cleaners, 91
Detonator fillers, 91
Detonator packers, 91
Devil operators (felt hats), 10, 91
Diamond cutters, 9, 10, 17
Diamond polishers, 86
Dichloroethylene workers, 61
Digester-house workers (paper and pulp), 3, 4, 83, 126
Dimethyl sulfate makers, 31, 63, 92, 106, 127
Dinitrobenzol workers, 105
Dinitrophenol workers, 65
Dioxan makers, 66
Dippers, *see* Acid dippers
Dippers (gun cotton), 106
Dippers (rubber), 33, 34, 46
Dish-washers, 12
Disinfectant makers, 18, 28, 30, 34, 37, 43, 48, 52, 59, 60, 74, 91, 110, 113, 118, 126, 133, 138; *see also* Insecticide makers
Divers, 1, 43, 45
Doffers (textile), 3, 5, 10
Dog-pound workers, 11, 13
Dope workers, *see* Airplane dope makers
Dressers (glass), 3
Dresser tenders (textile), 3, 4, 5
Driers, 4, 43, 45
Driers (felt hats), 4, 92
Driers (lacquer), 15
Driers (rubber), 33, 34, 44
Drier workers (foundries), 45
Drillers (rock), 8, 9
Drivers, *see* Chauffeurs
Drop forgers, 3
Dry-battery workers, *see* Battery (dry) makers
Dry cleaners, 4, 26, 33, 34, 44, 46, 61, 70, 92, 109, 130, 131, 138, 142
Drying-room workers (miscellaneous), 4, 43, 45
Dye makers, 3, 4, 18, 20, 21, 25, 28, 29, 30, 31, 32, 34, 37, 40, 43, 46, 48, 52, 56, 59, 60, 63, 65, 66, 68, 74, 75, 76, 80, 83, 86, 90, 91, 92, 93, 94, 95, 96, 99, 105, 106, 109, 113, 114, 115, 118, 120, 124, 126, 127, 133, 138, 142, 143, 144
Dyers, 4, 20, 25, 26, 28, 29, 30, 33, 56, 70, 74, 80, 82, 86, 90, 92, 106, 109, 113, 118, 120, 125, 136, 143, 144; *see also* Mordanters *and other preparatory process workers*

Electrical-condenser makers, 49, 51
Electrical-transformer makers, 49, 51
Electricians, 15, 110
Electric-induction-furnace workers, 91
Electric linemen, 5, 15; *see also* Cable splicers
Electrode makers, 10, 128
Electrolytic-process (copper) workers, 31
Electroplaters, 5, 29, 30, 31, 33, 34, 41, 44, 51, 56, 60, 75, 80, 82, 86, 90, 101, 106, 119, 127, 130, 138
Electrotypers, 4, 9, 10, 25, 29, 86; *see also* Electroplaters
Elevator runners, 17
Embalmers, 74, 91
Embalming-fluid makers, 91
Embossers, 91
Embroidery workers, 6, 86
Emery-wheel makers, 9, 86
Enamelers, 3, 5, 8, 17, 26, 29, 30, 33, 34, 44, 45, 56, 86, 90, 101, 130, 142

TABLE 3 (*Continued*)

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Enamel makers, 26, 29, 30, 32, 33, 34, 44, 45, 56, 80, 82, 86, 90, 94, 106, 130, 142
Engineers (stationary), 3, 4, 9, 45
Engravers, 6, 9, 17, 34, 58, 80, 86, 91, 106, 109, 124, 127
Etchers, 31, 80, 82, 106, 113, 127
Ether makers, 127
Ethyl benzene makers, 67
Ethyl bromide makers, 68
Ethyl chloride makers, 68
Ethylene dibromide makers, 37, 69
Ethylene dichloride makers, 70
Ethylene oxide makers, 71
Examiners using fluoroscope or X ray, 16
Excavation workers, 12
Explosives workers, 5, 18, 20, 25, 26, 27, 28, 29, 34, 37, 43, 44, 56, 59, 65, 74, 86, 91, 92, 105, 106, 107, 113, 116, 118, 120, 127; *see also particular occupation*
Exterminators and fumigators, *see* Insecticide makers
Extractor operators (soap), 4, 5
Extractors (gold and silver), *see* Gold and silver refiners and extractors
Extractors (oils and fats), 20, 33, 34, 44, 70, 130, 138

Farmers, 11, 12, 14, 30, 42, 86, 103
Fat renderers, 4, 11, 22, 83, 88, 110, 127
Feather curers, 10, 30
Feather workers, 10, 13, 28, 30, 33, 34, 92, 126, 142
Felt-hat makers, 3, 4, 10, 45, 91, 92, 106, 127; *see also particular occupation*
Felt makers, 3, 11, 83
Ferrosilicon workers, 30, 31, 117
Fertilizer makers, 5, 8, 9, 10, 11, 13, 22, 25, 30, 31, 34, 42, 43, 60, 80, 82, 83, 88, 90, 103, 106, 126, 127; *see also* Phosphate-mill employees
Fiberizers (asbestos), 7
Fiber workers, 10
Filament makers and finishers (incandescent lamps), 26, 45, 92, 133
File cutters, 9, 86
Filers, 9, 29, 86
Filling-station workers, 33, 45, 86, 132
Film makers, *see* Photographic film makers
Filter-press workers, 5
Finishers (leather), 10
Fire-extinguisher makers, 43, 46, 68, 69, 93
Firemen (city), 3, 4, 5, 45, 115, 126
Firemen (stationary), 3, 4, 9, 15, 45
Fireworks makers, 29, 30, 32, 90, 91, 116, 118, 133; *see also* Explosives workers
Fishermen, 4, 5, 13, 128
Fish-market workers, 13
Flangers (felt hats), 4, 45
Flatteners (glass), 3
Flavoring-extract makers, 26, 27, 34, 40, 105
Flax-rettery workers, 83
Flax spinners, 3, 10
Flint workers, 8, 9
Floor molders, *see* Molders (foundry)
Floor-polish makers, *see* Polish makers
Flour-mill workers, 10, 12
Flue cleaners, 9, 45, 126, 128
Flue-dust recoverers (sulfuric acid manufacture), 133
Flush tenders (aluminum), 5
Fly-paper makers, 30
Food irradiators, 15
Forestry workers, 11, 12, 14
Forgemen, 3
Formaldehyde workers, 74
Formers (felt hats), 10, 91
Formic acid workers, 75, 109
Foundry workers, 3, 8, 9, 15, 43, 45; *see also particular metal*
Freight handlers, 11
Frosters (glass and pottery), 56
Fruit-essence makers, *see* Flavoring extract makers
Fruit preservers, 126

TABLE 3 (*Continued*)

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Fullers (textiles), 34, 46, 62, 130
Fulminate mixers, 60, 91
Fumigant makers, *see* Insecticide makers
Fumigators and exterminators, *see* Insecticide makers
Fur carders, 10, 11
Fur clippers, 10, 11
Fur cutters, 10, 11
Fur handlers, 10, 11, 83, 91
Furnace workers, 3, 9, 15, 43, 45; *see also particular metal*
Furniture polishers, 10, 17, 26, 33, 56, 92, 112, 142
Fur preparers, 10, 11, 74, 91, 106
Fur pullers, 10, 11
Fused-quartz workers, 8
Fusel-oil workers, 27

Galvanizers, 3, 5, 22, 25, 30, 31, 33, 80, 86, 106, 126, 127, 138, 147
Garage workers, 22, 33, 45, 86, 132
Garbage workers, 13
Gardeners, 14, 30, 42, 86, 103
Gas (illuminating) workers, 3, 4, 25, 31, 34, 45, 60, 82, 83, 113, 128, 138
Gasoline blenders, 28, 33, 34, 67, 69, 86, 105, 132
Gasoline-engine workers, 22, 33, 45
Gas purifiers, 25, 60, 83, 113
Gassers (textile), 45
Gatherers (glass), 3
Gelatine makers, 11, 22, 126
Germicide makers, *see* Disinfectant makers
Gilders, 26, 33, 34, 60, 91, 92, 106, 120
Glass blowers, 3, 9, 15
Glass colorers, 41, 56, 57, 122. 129
Glass cutters, 5, 9
Glass etchers, 74, 82
Glass finishers, 5, 9, 80, 82, 86, 127
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Tree sprayers, *see* Sprayers (trees)
Trichloroethylene workers, 138
Trinitrotoluol makers, 34, 105
Tube makers (glass), 3
Tubulators (incandescent lamps), 45
Tumbling-barrel workers, 8, 9
Tunnel workers, 1, 6, 8, 9, 43, 83, 106
Turners-out (glass), 3
Turpentine extractors, 3, 142
Type cleaners, 33, 92
Type founders, 29, 86
Type melters, 22, 86
Typesetters, *see* Compositors
Typists, 17

Ultramarine blue makers, 126
Upholsterers, 10, 11, 92
Uranium miners, 16, 143
Uranium workers, 16, 143

Vanadium steel workers, 3, 144
Vapor curers, *see* Vulcanizers
Varnishers, 18, 20, 26, 27, 28, 33, 34, 40, 46, 61, 70, 75, 86, 90, 92, 130, 138, 142
Varnish makers, 4, 18, 20, 22, 25, 26, 27, 28, 30, 32, 33, 34, 40, 44, 46, 49, 51, 66, 70, 75, 76, 79, 86, 90, 92, 94, 110, 113, 124, 125, 130, 138, 142
Varnish-remover makers, 33, 34, 62, 78, 111, 130
Varnish removers, 33, 34, 62, 78, 111, 130
Vatmen, 3, 5, 43
Vat varnishers, *see* Varnishers
Vault workers, 43
Velvet makers, 3, 30
Veterinarians, 11, 13, 14
Vignetters, 80
Vinegar workers, 18, 43
Vintners, 43
Vinyl chloride makers, 145
Vulcanizers, 4, 25, 28, 29, 33, 34, 43, 44, 46, 56, 83, 122, 125, 126
Vulcanizers (steam), 3, 5

Wallpaper printers, 3, 4, 30, 56, 86
Warehouse workers, 11
War-gas makers, 31, 34, 37, 52, 60, 63, 115, 118, 125
Warming-house employees (guncotton), 4
Washers, 5
Washers (metal), 33; *see also* Degreasers
Washwomen, 5, 17
Watch dial (luminous) painters, 16
Watchmakers, 6, 17
Water gilders, 91
Waterproofers (paper and textile), 33, 34, 46, 56, 74, 128
Water purifiers, 32, 48, 52, 110
Wax makers, 34, 49, 51, 110, 127, 130, 142; *see also* Petroleum
Wax-ornament makers, 23, 30, 56
Weavers, 10, 17
Weavers (asbestos), 7
Weighers, 9, 10
Welders, 3, 15, 24, 30, 34, 41, 45, 56, 58, 82, 85, 86, 89, 90, 91, 106, 110, 116, 117, 122, 147, 148
Well workers, 43
White-lead workers, 43, 86
Window-shade makers, 33, 34
Wire drawers, 30, 80, 127
Wirers (incandescent lamps), 26
Wood-alcohol distillers, 20, 45, 92
Wooden-heel workers, 11
Wood-last scourers (shoes), 10
Wood polishers, *see* Furniture polishers
Wood preservers, 30, 65, 91, 113, 127, 128
Wood stainers, 56, 86
Woodworkers, 10, 33, 92
Wool carders, 10, 11
Wool scourers, 4, 5, 11, 20, 25

TABLE 3 (*Continued*)

ALPHABETICAL LIST OF HAZARDOUS OCCUPATIONS WITH INDEX NUMBERS TO HAZARDS

Wool spinners, 10, 11
Wool workers, 10, 11; *see also particular occupation*
Wringers (guncotton), 106

X-ray-machine makers, 16
X-ray photographers, 16
X-ray technicians, 16
X-ray-tube makers, 16

Yeast makers, 18, 43, 82, 127

Zinc chloride makers, 31, 52, 80
Zinc-electrode makers, 91
Zinckers, 60
Zinc miners, 30, 86, 90; *see also* Miners
Zinc smelters and refiners, 3, 8, 9, 29, 30, 41, 45, 86, 90, 122, 129, 147, 148
Zoological technicians, 14

CHAPTER II

EVALUATING INDUSTRIAL ATMOSPHERIC HEALTH HAZARDS

For the purposes of industrial health engineering, the phrase industrial atmospheric health hazards includes (1) harmful atmospheric contaminants, (2) radiant energy other than heat, (3) temperature, (4) humidity, (5) illumination, and (6) noise. The bulk of the problems confronting the industrial hygiene engineering profession today are caused by atmospheric contaminants. Consequently, this chapter will be devoted to a brief discussion of the evaluation of health hazards from harmful air-borne materials. Some information on the evaluation of health hazards from items 2 to 6 inclusive will be found in later chapters which are devoted to the problems of radiant energy, heating and ventilating, illumination, and noise.

Evaluation. The expression "evaluation of the health hazard" is a very loose one and is generally employed to mean the determination of the concentration of harmful materials in the air surrounding the worker and comparing it with the maximum allowable concentration. The proper evaluation of a health hazard, however, is farther reaching than this. It should include the collection and study of all data, chemical, toxicological, and medical, which are available and then the estimate of the hazard. It must be borne in mind at all times that chronic occupational illnesses are caused by repeated daily exposures to low concentrations of toxic materials, frequently so low that they are not in the least objectionable to the worker. He, and many in management, are not aware that the exposure is hazardous. They think only in terms of overwhelming concentrations which cause acute poisoning. On the other hand, the worker will object strenuously to being exposed to safe concentrations (below the maximum allowable concentration) of irritating substances such as formaldehyde and ammonium picrate. This type of exposure, even though not harmful, deserves the attention of the engineer because a good worker is a contented worker, and he will not be contented if he is exposed to objectionable concentrations of irritating air-borne materials.

It is an inescapable fact that just as "the proof of the pudding is in the eating" so the existence of a real health hazard depends on whether workers are being poisoned or not. On the other hand, it is mere folly to depend entirely on medical records since (1) only too often proper medical examinations are not made and such records are not kept, (2) the harm done by some chemicals to various organs of the body is irreparable, (3) early poisoning by some toxic materials is not manifested by early signs or symptoms so that advanced poisoning may result before it appears in the medical examination, and (4) it has been shown in many studies that a careful appraisal of the worker's surrounding atmosphere provides an excellent index of the health hazard to which he is exposed. Consequently, there remains little doubt that periodic studies of the workers' exposures are worthwhile and necessary and that the results so obtained are a good index in lieu of, or in addition to, medical records of the existence and severity of atmospheric health hazards.

In addition to atmospheric studies and medical records there is another procedure which is very revealing of the severity of exposure to some few substances, such as lead. This is urinalysis. There is considerable controversy at present regarding the value of urine samples. This apparent difference of opinion is probably due largely to misunderstanding as to the method of sampling and the value of the results. Periodic urine samples which are collected by a standard technic and under well-controlled conditions will serve as a good index of the worker's absorption rate and therefore of his exposure. Those industrial hygiene engineers who have had considerable experience with urinalysis for lead feel that this procedure gives much worthwhile information with relatively little work.

Atmospheric Sampling. The existence or severity of an atmospheric health hazard depends upon the concentration of the harmful material in the air, the toxicity of the material, and the length of time the worker is exposed. Some writers [14, 15] also include the susceptibility of the worker as one of the factors determining the health hazard. Certainly the susceptibility of the individual is a most important factor in determining whether, or how soon, he will become ill, but, since little is known about this subject and since health hazards are usually based on the average individual, it can be omitted from the engineering considerations in deciding the existence or severity of health hazards.

Measuring the concentration of any material in the air involves two distinct steps—sampling and analysis. In some instruments, such

as the carbon monoxide indicator, the hydrogen sulfide detector, and the benzol indicator, both operations are performed essentially simultaneously by the same instrument and the atmospheric concentration is given directly. For the large majority of the contaminants, however, the procedure is much more laborious. Appropriate samples are first collected, and the amount of the contaminant in the sample is then determined separately, usually in a laboratory at some distance from the place of sampling.

Sampling is of two kinds: (1) collecting a known or measurable volume of the contaminated air from the breathing zone of the worker (sampling tubes), and (2) collecting the contaminant from a measured quantity of air taken from the worker's breathing zone (electrostatic precipitator, impinger, bubbler, and combustion apparatus). Owing to the different characteristics of many of the substances to be collected, there is need for a large variety of sampling procedures, methods, and technics. Furthermore, sampling methods are constantly changing to keep abreast of our growing knowledge in this field. The subject of sampling is so broad that volumes might be written on it alone, and for detail the reader is referred to standard works on the subject.[16, 17, 18] The sampling methods for a fair number of representative substances are summarized very briefly in table 4. This table is far from complete, but it will serve as a useful guide.

Collecting representative samples is not easy. It is an art in which there is no substitute for experience. Generally speaking, samples are collected for one or more of four reasons: (1) to determine the workers' exposures at all operations where potential health hazards are believed to exist—the industrial hygiene survey; (2) to determine the weighted average exposure of an individual who appears to have been made ill; (3) to determine what control procedures to employ; and (4) to study the efficiency of control installations or of parts thereof.

In making industrial hygiene surveys of a given industry, plant, or workroom an adequate number of samples is collected from the breathing zone of the workers at all operations where health hazards are believed to exist. A worthwhile survey of a medium to large industry may require from two weeks to two or more months. Sufficient samples must be taken at each potentially harmful operation on different days to assure representative results. A very minimum of three good samples taken on three different days is needed to evaluate one exposure, and as a rule more samples are needed. In-

TABLE 4

AIR SAMPLING FOR ANALYSIS OF CONTAMINANTS

Substance	Sampling Method	Collecting Medium	Sampling Rate (liters per minute)
Acetates	(See esters)		
Acetic acid	Fritted glass bubbler [a]	0.1% sodium hydroxide	2.0
Acetone	Fritted glass bubbler	0.5% sodium hydroxide	1.0
Acetylene tetrachloride	(See tetrachloroethane)		
Acid mists	(See specific acids)		
Alcohols	(See specific alcohols)		
Alkali mists	Fritted glass bubbler	Distilled water or 0.02 *N* HCl	2.0
Amatol	Midget impinger [b]	Diethylaminoethanol	2.83 [c]
Ammonia	Fritted glass bubbler	0.5% sulfuric acid or 0.02 *N* HCl	2.0
Ammonium chloride	Midget impinger Impinger	Distilled water Distilled water	2.83 28.3 [d]
Ammonium nitrate	Midget impinger	Distilled water	2.83
Ammonium picrate	Midget impinger	Distilled water	2.83
Amyl acetate	(See esters)		
Aniline	Two fritted glass bubblers	0.5% sulfuric acid [e]	1.0
Antimony compounds	Electrostatic precipitator Impinger [g]	 Distilled water	85 [f] 28.3
Arsenic compounds	Electrostatic precipitator Impinger	 Distilled water	85 28.3

Arsine	Fritted glass bubbler	Normal nitric acid	1.0
Asbestos	Electrostatic precipitator Impinger	 Distilled water or alcohol	85 28.3
Barium compounds	Impinger	Distilled water	28.3
Benzene (benzol)	Benzol indicator Sampling tube [h]		
Bromine	Fritted glass bubbler	0.1% sodium hydroxide	2.0
Butanone	Fritted glass bubbler	0.5% sodium hydroxide	2.0
Butyl acetate	(See esters)		
Butyl alcohol	Fritted glass bubbler	Distilled water	1.0
Cadmium compounds	Electrostatic precipitator Impinger	 Distilled water	85 28.3
Carbon dioxide	Sampling tube		
Carbon disulfide	Fritted glass bubbler Sampling tube (500 cc)	0.1 N alcoholic KOH	0.5
Carbon monoxide	Carbon monoxide indicator Sampling tube		
Carbon tetrachloride	Combustion apparatus Sampling tube (275 cc)	Sodium carbonate-sodium arsenite reagent	1.5
Chlorinated diphenyls	Combustion apparatus	Sodium carbonate-sodium arsenite reagent	1.5
Chlorinated naphthalenes	Combustion apparatus	Sodium carbonate-sodium arsenite reagent	1.5
Chlorine	Two fritted glass bubblers Midget impinger	Sodium hydroxide with arsenious acid Orthotolidine solution	0.5 2.83
Chlorine dioxide	Fritted glass bubbler	5% potassium iodide solution	1.0

TABLE 4 (*Continued*)

AIR SAMPLING FOR ANALYSIS OF CONTAMINANTS

Substance	Sampling Method	Collecting Medium	Sampling Rate (liters per minute)
Chloroform	Combustion apparatus Sampling tube (275 cc)	Sodium carbonate-sodium arsenite reagent	1.5
Chromic acid mist	Impinger	0.1% sodium hydroxide	28.3
Chromium compounds	Electrostatic precipitator Impinger	 Distilled water	85 28.3
Cyanide	Fritted glass bubbler	0.5% sodium hydroxide	1.0
Dichlorobenzene	Combustion apparatus	Sodium carbonate-sodium arsenite reagent	1.5
Dimethyl aniline	Two fritted glass bubblers	0.5% sulfuric acid	1.0
Dinitrotoluene (DNT)	Midget impinger	Diethylaminoethanol	2.83
Diphenylamine	Two fritted glass bubblers	0.5% sulfuric acid	1.0
Dusts	(See specific dust)		
Esters	Benzol indicator Fritted glass bubbler	(Special calibration) Ethyl alcohol	 1.0
Ether	Benzol indicator Sampling tube	(Special calibration)	
Ethyl acetate	(See esters)		
Ethyl alcohol	Fritted glass bubbler	Distilled water	1.0
Ethylene dichloride	Combustion apparatus Sampling tube (275 cc)	Sodium carbonate-sodium arsenite reagent	1.5

Fibrosis-producing dusts	Impinger Electrostatic precipitator	Distilled water or alcohol	28.3 85
Fluorine compounds—dusts gases	Electrostatic precipitator Fritted glass bubbler	0.1% sodium hydroxide	85 1.0
Formaldehyde	Fritted glass bubbler	0.1% sodium hydroxide	2.0
Free silica	Electrostatic precipitator Impinger	Distilled water or alcohol	85 28.3
Halowax	(See chlorinated naphthalenes)		
Hexachloroethane	Midget impinger	Ethyl alcohol	2.83
Hexanone	Fritted glass bubbler	0.5% sodium hydroxide	2.0
Hydrochloric acid	Fritted glass bubbler	0.1% sodium hydroxide	2.0
Hydrocyanic acid	Fritted glass bubbler	0.1% sodium hydroxide	2.0
Hydrofluoric acid	Fritted glass bubbler	0.1% sodium hydroxide	2.0
Hydrogen sulfide	Hydrogen sulfide detector Fritted glass bubbler	Cadmium chloride solution	2.0
Lead and most lead compounds	Electrostatic precipitator Impinger	5% nitric acid	85 28.3
Lead azide	Midget impinger	Ethyl alcohol	2.83
Magnesium (metallic)	Midget impinger	Distilled water	2.83
Magnesium compounds	Electrostatic precipitator		85
Manganese and compounds	Electrostatic precipitator Impinger	Distilled water	85 28.3
Mercury compounds	Midget impinger	Ethyl alcohol	2.83
Mercury vapor	Mercury vapor detector		

TABLE 4 (*Continued*)

AIR SAMPLING FOR ANALYSIS OF CONTAMINANTS

Substance	Sampling Method	Collecting Medium	Sampling Rate (liters per minute)
Metal fumes	Electrostatic precipitator		85
Methyl alcohol	Fritted glass bubbler	5% alkaline permanganate	1.0
Methyl butyl ketone	(See hexanone)		
Methyl cellosolve	Fritted glass bubbler	1.5% potassium dichromate in 50% H_2SO_4	1.0
Methyl ethyl ketone	(See butanone)		
Nitric acid	Fritted glass bubbler	0.1% sodium hydroxide	2.0
Nitrobenzene	Sampling tube	2 cc nitrating acid	
Nitrogen oxides	Sampling tube (275 cc)	10 cc 0.1 N H_2SO_4 plus 3 drops 3% H_2O_2	
Nitroglycerin	Midget impinger	Propylene glycol	2.83
PETN	Fritted glass bubbler	Triethylene glycol	1.5
Petroleum vapors	Benzol indicator Combustible gas indicator	(Special calibration) (Special calibration)	
Phenol	Two fritted glass bubblers	0.1% sodium hydroxide	1.0
Phosgene	Two fritted glass bubblers	0.1% sodium hydroxide	1.0
Phosphine	Two fritted glass bubblers	Bromine water	0.5
Potassium chlorate	Midget impinger	Distilled water	2.83
Propyl alcohol	Fritted glass bubbler	Distilled water	2.0
Quartz	Electrostatic precipitator Impinger	 Distilled water or alcohol	85 28.3

Silica (free)	Electrostatic precipitator Impinger	Distilled water or alcohol	85 28.3
Sodium oxalate	Midget impinger	Distilled water	2.83
Strontium compounds	Midget impinger	Distilled water	2.83
Sulfur chloride	Fritted glass bubbler	0.1% sodium hydroxide	1.0
Sulfur dioxide	Fritted glass bubbler	0.1% sodium hydroxide	1.0
Sulfuric acid	Fritted glass bubbler	Distilled water	2.0
Tetryl	Midget impinger	Diethylaminoethanol	2.83
Toluene (toluol)	Benzol indicator Sampling tube (275 cc)		
Triethylene glycol	Fritted glass bubbler	Potassium dichromate in 50% H_2SO_4	1.0
Trinitrotoluene	Midget impinger	Diethylaminoethanol	2.83
Xylene (xylol)	Benzol indicator Sampling tube (275 cc)		
Zinc compounds	Electrostatic precipitator Impinger	Distilled water	85 28.3

NOTES

a. Use coarse-porosity fritted glass bubblers.
b. Wherever the midget impinger is specified, the standard impinger can be substituted, but the midget is preferred.
c. The sampling rate is 0.1 cfm or 2.83 lpm.
d. The sampling rate is 1.0 cfm or 28.3 lpm.
e. Wherever two fritted glass bubblers are specified, the bubblers are to be used in series.
f. Sampling rate is 3 cfm or 84.95 lpm.
g. Wherever the standard impinger is specified, the midget impinger may be substituted, but the standard unit is preferred.
h. Sampling tubes are of various kinds: evacuated, air flushing, water displacement, etc.

dustrial hygiene surveys or studies of this type are made to determine where potential hazards exist so that control measures may be installed or improved as needed and/or to obtain data on exposures for correlation with medical findings to establish maximum allowable concentrations.[19, 20, 21, 22] When making an industrial hygiene survey it is helpful first to make a preliminary survey and an occupational

FORM C

NATIONAL DEFENSE INDUSTRIAL HYGIENE SURVEY*

WORKROOM SURVEY DATA

Page__________of__________

Name of Plant______________________________ Industry Code and No.______________

Department________________________ D/W______ S/D_______ Workroom No.________________

Informant's Name____________________ Surveyed by________________ Date________________

Occupation	Number of Persons			Nature of Job	Raw Materials and By-products	Exposure Code	Control Measures										Remarks
	M	F	T				Pos. Ven.	Neg. Ven.	Loc. Exh.	Enc. Proc.	Wet Meth.	Gas Mask	Respirat.	Pres. Hel.	Pro. Clo.	Other	
Total Brought Forward																	
Total																	

* FIGURE 1. Workroom Survey Form (*Courtesy U.S.P.H.S.*)

analysis.[23] Information as listed on suggested work sheets shown in figures 1 and 2 should be obtained by operation and by workroom. This information will serve to acquaint the surveyor with the industry being studied and to indicate where potential health hazards exist and where sampling need be done. Experience has demonstrated the value of such preliminary surveys particularly in any industry being studied for the first time.

The second type of sampling often involves the careful appraisal of the exposure of only one worker. This is done in an attempt to find the explanation for the illness of one worker who apparently has no excessive exposure or who has essentially the same exposure as other workers who show no signs of illness. It may be done also to find the reason for an epidemic of illnesses at operations which pre-

FORM B NATIONAL DEFENSE INDUSTRIAL HYGIENE SURVEY

PLANT SURVEY

Page No. ________ Date ________

Name of plant ________ Industry Code and No. ________

1. GENERAL

Department (room) ________ Type of Building ________

Building No. ________ Location ________

Operations conducted in room ________

________ Shifts worked ________

General impression as to crowding ________

2. SANITARY DATA

Dimensional	Cleaning Services
Floor area ________ ft²	Times per day ________
Net floor space ________ %	Sweeping dry ________
Height of room ________ ft	Sweeping wet ________
Area windows ________ ft²	Vacuum ________
Ratio windows to floor area ________	Washing ________
	Refuse disposal ________
Ft²/cap. ________	Cuspidor service ________

Personal Services

	M	F
Cloak rooms		
Lockers provided		
No. clothing changes provided per week		
Washing facilities: Type		
No. workers per wash faucet		
No workers per shower		
Drinking water: Type		

Toilet facilities
Type and No. ________ Illumination Vent. Cond.
Male
Female

FORM B (Continued)

Page No. ________ Date ________

3. VENTILATION

Natural ________ Type ________
Artificial ________ Type & No. ________

4. ILLUMINATION

Natural ________ General impression ________
Condition of windows ________
Artificial ________ General impression ________
Type & No. ________ Condition ________
Shadow or glare ________

5. SAFETY HAZARDS

6. FUMES AND GASES

7. DUSTY PROCESSES

8. SPECIFIC POISONS

9. EXPOSURES TO ABNORMAL TEMPERATURES, DAMPNESS, RADIATION, NOISE, ETC.

FIGURE 2. Environmental Survey Form (*Courtesy U.S.P.H.S.*)

viously caused no illness. The measurement of the health hazard to which a worker or workers are exposed involves the determination of the weighted average atmospheric concentration unless the exposure is essentially constant throughout the day. To do this the average concentration at each job is multiplied by the time at each job, and the sum of these values is divided by the total length of time worked daily. Hence

$$\frac{E_1T_1 + E_2T_2 + E_3T_3 \cdots E_nT_n}{T_1 + T_2 + T_3 \cdots T} = \text{Weighted-average daily exposure}$$

E, of course, represents the atmospheric concentration to a given material at n different jobs, and T represents the time in minutes or hours engaged at each job. When seeking the reason for what appears to be an unusual case of chronic poisoning, due consideration must be given to possible prior employment at different operations presenting more severe exposures. The foregoing formula may be used also in obtaining the weighted-average exposure over a period of years. This method is particularly useful for occupational diseases, such as silicosis and asbestosis, which require a long time to develop, but it must be used with caution when considering poisons since moderate exposure years earlier may have had no demonstrable effect on the illness, and, if included in the calculation of a weighted average exposure, might make the result meaningless.

The third type of sampling is relatively rare. If the person who conducts the sampling in the industrial hygiene survey also makes the recommendations for control, and if his survey sampling is adequate, no sampling of this type will be necessary except under unusual circumstances. If, on the other hand, the engineer whose responsibility it is to recommend and design suitable control equipment did not take part in the original evaluation of the hazard he may need a series of additional "spot" samples to permit selecting and designing the best equipment for control. For example, many operations which create atmospheric health hazards have one or more sources from which most of the toxic material escapes into the workroom air, along with many places from which some material escapes. Not infrequently, the relatively simple procedure of eliminating the few major sources of contamination will reduce the atmospheric concentration to a safe level while to control all sources would be quite difficult. Appropriate sampling to find the points of escape where they are not evident is well worth the trouble.

The fourth type of sampling is done to determine how much improvement was effected by a different hood, an increase in the quantity of air flow, relocation of the operation, etc., and to study the retention efficiency of filters or collectors of all types. It is frequently done routinely as a part of the industrial hygiene survey or resurvey but is called for also whenever there are changes in operation, materials, or control measures.

Sampling Errors. Errors in sampling are many, and no attempt will be made here to cover them all. Experience or practice with suitable supervision is the best antidote. There are two serious errors which beginners apparently are heir to and which frequently produce high results. The first concerns the sampling period and the second the sampling location. The length of the sampling time is dictated by two considerations. The period must be long enough to obtain a sample which can be analyzed accurately, and it must be governed also by the cycle of the operation being studied. The chemist who analyzes the samples can compute the minimum sampling period for any substance assuming that the concentration in the air will be not less than the maximum allowable concentration. Such suggested minimum sampling times for a number of substances may be found in reference 14. Armed with this information, however, the beginner is prone to sample for the specified time rather than to sample by cycle of operation regardless of whether the operation releases the contaminant at a fairly uniform rate or at a very irregular rate. If the nature of the operation is such that the rate of contaminant release varies up and down throughout each complete cycle of operation, the sample must be collected for a given number of cycles, which is usually some odd period of time in minutes. Otherwise the result will be meaningless and may be very high or low depending upon what part of the cycle was sampled. It seems to be common practice, for example, for the novice to sample only while the worker is doing the dusty part of an operation, such as charging a kettle, even though the worker spends a fair part of his time going to the supply room for additional material. To appraise the worker's average exposure the sampling must be done from his breathing zone throughout one or more complete cycles of operation, or the concentration must be determined for the different parts of the cycle of operation and the average exposure then determined on the basis of the time devoted to each phase of the operation, as explained earlier.

The second serious error is that of hunting for dust. In the evaluation of a potential health hazard the object is to measure as accur-

ately as possible the concentration of the contaminant in the air breathed by the worker. Yet it is not unusual to see the novice sampling near the worker but where dust is obviously escaping, even though the bulk of this dust never reaches the breathing zone of any worker. This erroneous procedure can be avoided by holding the sampler inlet as close to the nose of the worker as possible and ignoring the source of dust.

A common error when sampling from some part of the exhaust system, such as in a duct or collector, particularly when using the midget impinger, results from failing to increase the suction on the impinger gage by the amount of negative pressure existing at the sampling point. Even though the actual rate of flow can be computed very easily if the negative pressure at the point of sampling is known, the efficiency of the sampler is affected an unknown amount and the results obtained are of little value.

Analysis. Depending upon the nature of the sample or the material sampled the analysis may be done gravimetrically, colorimetrically, volumetrically, chemically, spectrographically, or by count. With the exception of dust counting the analyses are generally not within the scope of the engineer and will not be discussed. Standard reference books on analytical methods are available if needed.[16, 18, 24]

Experience has demonstrated that for fibrosis-producing dusts, such as asbestos, silica, quartz, the number of particles is more significant than the weight of the dust as an index of the severity of the health hazard. Consequently, these dusts, and nuisance dusts, such as emery and silicon carbide, which are not absorbed into the blood stream, are quantitated by counting under a microscope. Various methods of sampling fibrosis-producing dusts have been used in the past, but the common practice at present is to sample with the standard or midget impinger or with the electrostatic precipitator.[25, 26, 27, 28, 29]

Dust Counting. The technic of dust counting is not simple and requires considerable practice to become proficient. For detailed information on the procedure the reader should consult a standard reference, such as 25, 30, 31, 32, or 33. Briefly, the dust count or number concentration of dust particles in the air is measured as follows: The sampling liquid from the impinger, or the liquid used to wash out the precipitator tube, is made up to a measured volume and shaken vigorously to get a uniform dispersion of the dust throughout the liquid medium. At least two counting cells[34] are prepared from each sample and allowed to settle 20 to 30 minutes

before counting. Dunn or Sedgwick-Rafter cells are most widely used today. Although dark-field microscopy is used to a limited extent,[35] the light-field method (either direct or by projection on a screen) has been accepted more or less as standard. A suitable ocular micrometer[36] is used, and the usual magnification for direct counting is 100 diameters (7.5 × eyepiece, 16-mm objective, and 178-mm tube length). Five different fields are counted in each cell, each field measuring 0.5 mm square. The samples are diluted so that the number of particles per field will average about 50 to 75, and blank counts on an unused sample are subtracted from the results. If the individual counts vary too greatly one from another (more than about 25% from the average), another cell should be prepared and counted. If only one field count differs widely from the others it may be discarded and a substitute field counted, provided the average for the cell checks that for the other cell of the same sample. The counts on the two different cells from a given sample should not differ by more than about 10%. This particle count (with the blank subtracted) represents the number of particles in 0.25 cu mm of liquid. When multiplied by 4000 and by the volume of the liquid sample in cubic centimeters and then divided by the volume of air sample in cubic feet, the result is the dust concentration per cubic foot of air.

Hence

$$\text{mppcf}\,^* = \frac{\text{Average count} \times \text{Volume of sample in cc}}{250 \times \text{Volume of air sample in cu ft}}$$

Dust Size and Composition. Although not of great concern with dusts of the poison type, particle size of fibrosis-producing dusts is very important. Experience and research have indicated that the potency of silica particles increases as their size decreases and that those above 5 or 10 microns are of no concern. Consequently, particles above 10 microns in average size should not be counted. Furthermore an average particle size distribution[25, 37] determination should be made on dust of this nature to be considered along with the count and composition in assessing the health hazard involved.

Most fibrosis-producing dusts found in the industrial atmosphere are not 100% silica (free or uncombined) or asbestos but contain a portion of other less harmful dusts. Thus in foundries where much sand is used and where silicosis may be found, the percentages of silica in the atmospheric dust usually are quite low.[38] To assess

* Millions of particles per cubic foot of air.

properly the potential health hazard existing at any operation it is, therefore, necessary to determine also the percentage of silica present. For this purpose an analysis of the bulk product (raw material) is unsatisfactory and even settled dust (rafter samples) does not have the same composition as the air-borne material.[39] Samples of air-borne dust suitable for petrographic or X-ray diffraction analysis must be collected of all fibrosis-producing dusts by some device, such as the electrostatic precipitator, a cloth- or paper-bag filter, or the IHF dust sampler.[40] There is also some evidence to indicate that only the air-borne dust under 5 microns in size should be analyzed for the free silica content to accurately estimate the hazard.[40] Of the several methods which may be used to determine the free silica content of an industrial dust[41, 42] petrographic microscopy and X-ray diffraction are most common.

CHAPTER III

PRINCIPLES OF CONTROL AND METHODS EMPLOYED

The control of occupational diseases is the joint responsibility of the engineer and the physician. It is best accomplished by controlling the exposure and the worker. By pre-employment and routine periodic medical examinations, by rotation of workers, by supervision of nutrition, diet, and personal hygiene, and by education, the physician plays an important part in the prevention of occupational diseases through controlling the worker. Important as these measures may be, it is generally agreed that they are secondary to the control of the hazard. If the hazard is severe, control of the worker alone will either not prevent occupational illnesses or it will jeopardize competitive production. If, on the other hand, the exposure is controlled adequately, less-frequent periodic medical examinations and less-strict supervision of diet and personal hygiene will be needed. Dr. Alice Hamilton[43] states, for example: "Since this is so [most poisoning is caused by *inhalation—author's note*], it *follows that the* air of the factory is of chief importance, and to keep it free from dangerous dusts, fumes, and gases is the first measure of protection; all others are secondary. If the worker is breathing contaminated air, he cannot be saved from poisoning or silicosis by the best of washing facilities, working clothes, good lunchrooms, and so forth. It is the air that must be made clean and kept so." Drs. Sayers and Jones in discussing silicosis and similar dust diseases[15] state: "Although we have mentioned the medical phase of control first, it is of secondary importance in effectiveness compared to that which is accomplished by engineering methods." Mr. V. P. Ahearn, in discussing the increasing importance of industrial health in industrial relations,[44] said: "Ventilation.—This seems like a rather small thing to a great many people, but I am confident that, at the working level, the lack of adequate ventilation has done as much to contribute to poor labor relations as anything." It is apparent, therefore, that the importance of industrial atmospheric sanitation cannot be overemphasized.

Measures for preventing the inhalation of excessively contaminated air have been discussed by many authors,[25, 30, 45, 46, 47] and there are about as many different classifications of these methods as there are papers on the subject. The principles expounded, however, are always essentially the same. They may be divided conveniently into three main groups as follows, depending upon the avenue of approach:

1. Eliminating the sources of contamination or reducing the amount.
   a. Building and equipment design, alteration, and maintenance.
   b. Substitution of less-toxic materials.
   c. Process or operation changes.
   d. Housekeeping.
2. Prevention of contaminant dispersion.
   a. Segregation of hazardous processes.
   b. Enclosing the hazardous processes.
   c. Wet methods.
   d. Local exhaust ventilation.
   e. Equipment maintenance.
   f. Worker education.
   g. Housekeeping.
3. Protecting the worker.
   a. Equipment alteration.
   b. General ventilation.
   c. Respirators.
   d. Worker education.

The control of an atmospheric health hazard is rarely accomplished by a single measure; it usually involves the use of a combination of methods.

Eliminating the Sources of Contamination. Obviously, the most successful approach to the problem of industrial atmospheric sanitation lies in *the design or alteration of plant and equipment* so that the control features are engineered into the structure and machinery. Factories constructed without due consideration to keeping the air clean, and existing plants, preclude the most efficient use of engineering-control knowledge. Much control equipment, installed on "unprepared" machinery even if carefully planned, is makeshift at best and has all the features of the proverbial "sore thumb." Probably the most important single avenue to better atmospheric sanitation lies in the education of the industrial equipment and machinery manufacturers so that at least the basic elements of control equipment are included as an integral part of each machine which is known to produce or disperse dusts, fumes, smokes, mists, gases, or vapors. Some action in this connection is in progress, but the surface is only being scratched. There appears to be no more justification for the

sale of a piece of factory machinery which is not a relatively complete and safe item in itself than there would be to sell an automobile minus the lights, brakes, horn, and windshield just because it can be used without them. Fortunately the trend today is in the right direction. Many new plants are being laid out with the atmospheric-sanitation problem in mind. Also a few industries which are undertaking industrial hygiene on a long-term basis are slowly mechanizing and modernizing their existing plants to increase production, eliminate arduous labor, and reduce atmospheric pollution. Fully as important as the original design of any piece of equipment is its maintenance. Deterioration, wear, corrosion, abrasion, and shock result in inefficient operation unless maintenance is good. In the smaller industry, maintenance is too frequently left to the user of the equipment. This is not a satisfactory procedure. All maintenance work should be made the responsibility of one man or one department.

A very effective method of control is *the substitution of nontoxic for toxic materials.* The application of this method is very limited in scope because of the basic requirements on which materials are usually selected. It should, however, always receive due consideration since it is both effective and usually inexpensive. Yet, for this very reason, the engineer or chemist must guard against overdoing substitution. It is generally agreed that any material, be it ever so harmful, can be handled safely if properly engineered. This feeling has been verified in practice by the experience of the atomic-bomb plants and the military explosives manufacturing and loading plants.[48] As substitution of less-toxic materials frequently runs counter to quality control in production it must be recommended with caution, particularly since other methods are available for the adequate control of hazards. Examples of successful substitution of less-toxic materials are the substitution of steel grit for sand in abrasive blasting; artificial abrasive grinding and polishing wheels for sandstone wheels; nonsilica parting compounds for siliceous compounds in foundries; petroleum naphtha or toluol for benzol in the lacquer, ink, and rubber cement industries; Stoddard solvent for carbon tetrachloride in dry cleaning; quartz-free or low-quartz minerals for sand under mine locomotives;[49] and relatively insoluble lead compounds for lead oxide in paints and ceramic glazes. Table 5 indicates what has been accomplished in one industry where sand was replaced by steel shot for abrasive blasting.[50]

A *change in the process* can sometimes be used to elimniate or control a health hazard. Such change frequently involves major changes

in other parts of the production line, and this control measure is therefore very limited in scope. Examples are controlling the temperature and speed of chemical reactions so that the rate of mist, gas, or vapor production is decreased; welding, crimping, riveting, or otherwise joining to eliminate soldering operations; and changing from manual batch charging to machine and hopper charging.

TABLE 5

DUST CONCENTRATIONS IN VICINITY OF AIR-PRESSURE BLASTING DEVICES USING SAND AND STEEL SHOT

Device	Average Dust Concentration (millions of particles per cubic foot of air)	
	Steel Shot	Sand
Barrels	14.7	28.7
Cabinets	8.6	23.2
Tables	11.3	25.2
Inside sand-blast room	155	969

More can be done by *good housekeeping* to eliminate sources of contamination, particularly dusts and fumes, than is commonly realized. In dusty industries or workrooms where dust is continuously settling on all surfaces which approach the horizontal, and collecting on vertical surfaces, good housekeeping in the form of vacuum cleaning, wet washing, and sometimes brushing prevents this material from being redispersed into the air. The amount of dustiness which is contributed to the air of dusty industries by the continual redissemination of the settled material is sometimes more than 50% of the total dust concentration.[30] Yet this dust can be prevented from getting into the air very readily by constant cleaning. Painting the walls a light color, improving the illumination, and oiling or wetting the floors are effective in promoting good housekeeping. While good housekeeping alone is seldom sufficient to control existing hazards, experience has shown that the housekeeping in most plants is a good index of the industrial hygiene program.

Prevention of Contaminant Dispersion. Many industries have operations which produce considerable atmospheric contamination but which require the immediate attention of only a relatively small

number of workers. If located indiscriminately throughout the plant or if conducted at certain times, such operations expose many other workers to a needless amount of atmospheric contamination. By *segregating or isolating these operations,* only those few workers engaged there will be exposed to the hazard, and they may be protected by means of respirators. Also the segregation or bunching of hazardous operations aids materially in the effective application of local exhaust ventilation or other control measures. The usefulness of this measure is so obvious that examples are scarcely needed. Blasting in mines at the end of the shift so that the gases and dusts will have settled or dissipated by the time the workers return, sweeping and cleaning at night when other workers are not on the job, shaking out foundry castings at night when most workers are off the job, and locating the plating or degreasing tanks in separate rooms are common examples.

Enclosing an operation might be considered an extreme form of isolation. The contaminant or contaminated air is prevented from reaching the breathing zone of any workers except in rare instances when one or two men may be exposed within the enclosure. It is superior to segregation or isolation since it acts nearer the source of contamination. In one instance the simple expedient of attaching a loose cover for the containers being filled to the end of a canvas discharge chute from a gyratory screen reduced the dust concentration in the screen room by well over 50%.[51] A good illustration of complete enclosure is shown in figure 3. In this instance a toxic and highly explosive material was transferred from 50- to 5-lb containers in a complete enclosure. The large cans were mounted on a frame in the top of the device shown in the figure, and after closing the door the contents were dropped into the hopper by rotating the handle. Measured quantities were then dropped into the small cans through the dust-tight corrugated hose shown in the illustration. The two wooden handles directly above the corrugated hose were slide gates which served to close and open the top and bottom of the measuring device. Hence by closing the lower valve and opening the upper one the material from the hopper filled the section between the slides which served as the measuring device. By closing the upper slide and opening the lower one the measured quantity of material was charged into the small container. This arrangement reduced the atmospheric concentration of the toxic material from a harmful level to almost nothing. Process enclosure has been found particularly successful at abrasive-blasting operations, such as barrel and cabinet

types of equipment which operate on the batch basis. The equipment is closed tight during the cleaning operation and is open only for charging and discharging after the abrasive blasting has been discontinued. This method of control does not find wide application

FIGURE 3. Dust Control by Enclosure of the Operation

except in conjunction with local exhaust ventilation which will be discussed later.

Wetting dust with water or other liquids is probably the oldest method of control. It was practiced in the pottery industry in Great Britain as early as 1713. Wet drilling and water sprays have been widely employed in mining operations in recent years. The use of water sprays in quarrying operations also has been reported recently.[52] Substantial reductions in the dust concentration have been

reported at wet-grinding operations[53] and at wet-drilling operations in mining,[54] but even then the atmospheric concentrations were still greatly in excess of the maximum allowable concentration. The effectiveness of wet methods for dust control depends upon two factors —wetting the dust, and proper disposal of the wetted dust. Some dusts are hard to wet and unless wetted will not be captured. Even if the dust is wetted satisfactorily it is necessary to collect and dispose of the wetted material before the liquid evaporates and the dust is again redispersed by air currents, walking, or blasting. In mines, for example, the dust from the wet-drilling operations settles out as the water flows away, and collects also as water droplets on the walls from where it is readily redispersed. Even though wetting of the dust must be recommended with discretion, it has been found an effective dust control aid in rock drilling, blasting, crushing, screening, materials transfer, foundry shakeout, core knockout, and abrasive blasting, and the addition of moisture to molding sand decreases greatly the amount of dust produced while making molds.

Local exhaust ventilation is probably the most important single method of preventing industrial atmospheric pollution. Yet the principles involved and the bases for adequate design are so badly understood that an unbelievingly large percentage of the installations made in recent years are unsatisfactory or inefficient. It was this fact more than any other, as indicated in the Preface, which prompted this book. Owing to the importance of local exhaust ventilation it will be discussed separately in Chapters V and VI.

Like all other types of equipment, that employed to control health hazards requires *constant checking and maintenance.* It should be included with other equipment in the cleaning and maintenance schedule. Dust collectors, fans, and in many instances ductwork require periodic cleaning to obtain satisfactory operation. Bent hoods and leaky or damaged ductwork and enclosures should be repaired promptly. Blast gates and dampers, if used, should be locked in position, but even then they need constant watching to see that the setting is not altered by the workers and the balance of the system thereby disturbed. Only too frequently management invests substantial capital in good control equipment and then either through complacency or lack of understanding proceeds to forget all about it until faced with a case or epidemic of occupational illnesses. The answer, and the only way to protect their investment, is periodic checking and maintenance just as is done with production equipment.

Very few if any measures or installations for the control of atmospheric pollution are foolproof. Much depends on the attitude of the worker. A cooperative, interested, and well-trained worker can accomplish much with any control equipment, whereas the indifferent, lackadaisical, untrained worker produces the maximum amount of atmospheric contamination with any control device. The solution lies in the *education of the worker.* This is an unending task and becomes very discouraging if labor turnover is high. Nevertheless it is the key to the really successful operation of atmospheric sanitation equipment. As a rule the labor turnover will be much less if the working conditions are good. Therefore, proper education of the worker is the first step in a chain of events which lead to a satisfactory educational program. (The properly instructed worker produces less atmospheric pollution, which results in less labor turnover, which in turn results in a more satisfactory educational program.) To be successful the education of the worker must begin the day he is employed. If he is permitted to begin his work without proper instruction in the performance of his tasks he will form faulty habits of operation which require much effort to undo. On the other hand the educational program must not cease as soon as the worker has been trained in the correct procedure of doing his job. It must be continued throughout his period of employment to keep him on his toes and to prevent him from falling into a faulty routine. Examples of what can be accomplished in atmospheric sanitation by worker education are unnecessary—they are quite obvious. Any operation (whether it be provided with control equipment or not) which produces or releases an atmospheric contaminant can be done, and should be done, in a manner which results in the escape of as little material as possible into the workroom air.

Good housekeeping will serve to prevent the dispersion of atmospheric contaminants. However, it is considerably more important in eliminating sources of contamination and was discussed previously in that connection.

Protecting the Worker. Most industrial machinery or equipment which produces or releases harmful contaminants can be *engineered either in the original design or by alteration of existing installations* to decrease the worker's exposure. In many instances, however, the reduction of exposure is not sufficient to eliminate the hazard, and other control measures are needed. Yet there are some operations where this principle may be applied to render the worker's exposure harmless. Examples are the use of mirrors and/or extensions on operating handles to permit the worker to stand clear of the escap-

ing contaminant; arranging all hot processes so that the operator stands beside rather than above the process; and locating a fan diagonally to the rear and to the side of the worker to blow the relatively clean workroom air through his breathing zone and to carry the highly concentrated contaminant from the operation he is doing away from him, or locating the terminal of a supply duct between the operator and the source of contamination to blow the contaminated air away.

General ventilation is second in importance only to local exhaust ventilation. It is particularly well adapted to certain contaminants and certain operations and is unsatisfactory for others. Owing to its importance and the fact that it is frequently misused by ventilating engineers, the subject of general ventilation will be covered in some detail in the following chapter.

Respiratory protective devices have a distinct place in the field of industrial health engineering. That they are a last line of defense can hardly be denied. Nevertheless, where they should be used, how they should be selected, and how they should be used and maintained is understood adequately by only a small number of industrial hygiene engineers. Owing to their relatively low cost as compared with most other control measures, and the fact that they can be employed on shorter notice than most other control measures, they are very much misused. Consequently, an entire chapter (XII) is devoted to a thorough discussion of this subject.

The *education of the worker* for his own protection is fully as important as to prevent the creation of unnecessary dust, fumes, mist, gases, or vapors. He must be told which contaminants are harmful and sold on the idea of avoiding the higher concentrations. Careful and continuous education is necessary to get workers into the habit of standing upwind of all operations which produce or release considerable material, such as spray painting, welding, cleanout and other maintenance operations, and handling bulk materials; also to keep his face as far from the point of operation as possible, or out of the line of throw or movement of the contaminant.

It should be apparent from the foregoing that the proper control of atmospheric contaminants is not easy. Flash opinions are frequently worth just about what they cost—nothing. Experience is, of course, invaluable, but even the experienced engineer must usually make a careful analysis of the circumstances existing at the operation in question before deciding upon control measures, owing to the tremendous lack of uniformity of conditions existing at similar operations in different industries or different factories of the same industry.

CHAPTER IV

GENERAL VENTILATION

Ventilation as defined by the *ASHVE Guide* [2] is "the process of supplying or removing air by natural or mechanical means, to or from any space." The term general ventilation implies that the air is supplied or removed from a general area, space, room, or building as contrasted to specific or local exhaust ventilation. For the purpose of design calculations, general ventilation is of two types—that for temperature, humidity, odor, and comfort control; and that for the control of atmospheric contamination. The construction of such systems is somewhat similar, but the design considerations have little in common. This chapter will be devoted to general ventilation for atmospheric sanitation. Ventilation of the other type is covered briefly in Chapter XIII.

Air enters and escapes continually from all rooms and buildings through doors, windows or window cracks, and other openings. If this air exchange is caused by natural conditions it is natural ventilation, and if it is produced by fans or other mechanical means it is artificial or mechanical ventilation. Within rooms or buildings the air is kept in circulation by temperature differences, by pressure differences, by movement of occupants and equipment, and/or by fans.

Atmospheric Sanitation through General Ventilation. In factories or workshops where some of the processed material is escaping continuously into the air, the concentration in the air will be governed by the rate of escape of the material and rate of air movement into and out of the building—the general ventilation rate. If only a small amount of material is escaping, natural ventilation is often sufficient to keep the atmospheric concentration at a safe level, unless the material is unusually irritating or toxic. If the concentration of the contaminant is above the maximum allowable concentration it frequently can be reduced to a safe level by increasing the ventilation rate to a value which can be calculated readily if certain conditions are known, namely, the existing ventilation rate and the

rate at which the contaminant escapes. It becomes evident at once, therefore, that general ventilation is a satisfactory control measure if the rate of contaminant production is not excessive in terms of the air required to maintain a safe atmospheric concentration. And, since to be effective the contaminant must be reduced to a safe level before the air in which it is carried reaches the breathing zone of any worker, it is likewise evident that general ventilation will not be satisfactory to control major sources of toxic contamination in close proximity to any worker. Hence the use of general ventilation is limited by these two factors—total amount of contaminant, and degree of concentration of the contaminant at sources near workers.

It must be kept in mind, of course, that practically all buildings have a certain amount of general ventilation, whether it be natural or mechanical. In a fair number of these, atmospheric health hazards do not exist solely because of the general ventilation; very little fume, vapor, or dust is required to produce an unsafe atmosphere in an air-tight space. An unusual example of the effectiveness of general ventilation in the control of many and varied scattered sources of a highly toxic fume and dust is given in reference 55. In this instance the lead dust and fumes from the linotype and monotype rooms of the Government Printing Office were controlled satisfactorily by general ventilation at the rate of about 25,000 cfm (about 15 air changes per hour) for each room (see figures 4 and 5). Even though much lead was processed (including melting) the pot temperatures were low enough to produce only a small amount of lead fume, and the other sources of contamination were minor and scattered.

General ventilation for atmospheric sanitation is frequently called dilution ventilation. This is a very descriptive term since, as indicated in the preceding chapter, it acts not by eliminating or reducing the amount of contaminant produced or by preventing the contaminant from entering the general workroom air, but rather by reducing the concentration of the contaminant in the air through dilution of the excessively contaminated air with relatively clean air. If this simple fact is thoroughly appreciated much grief will be avoided by not attempting to use general ventilation as the sole control measure where it can be shown by direct calculation to be unsatisfactory.

Misuse of General Ventilation. General ventilation is misused to a great extent in the air sanitation field at present. This is under-

standable since the problem of dust, fume, or gas control is frequently laid on the doorstep of the plant or ventilating engineer who knows relatively little about other control measures. He frequently thinks only in terms of air changes per hour—10 air changes per hour being a fair ventilation rate, 30 per hour a high rate, and 60 per hour a miniature hurricane. It has been the author's experience that to convince some of these engineers that even 60 air

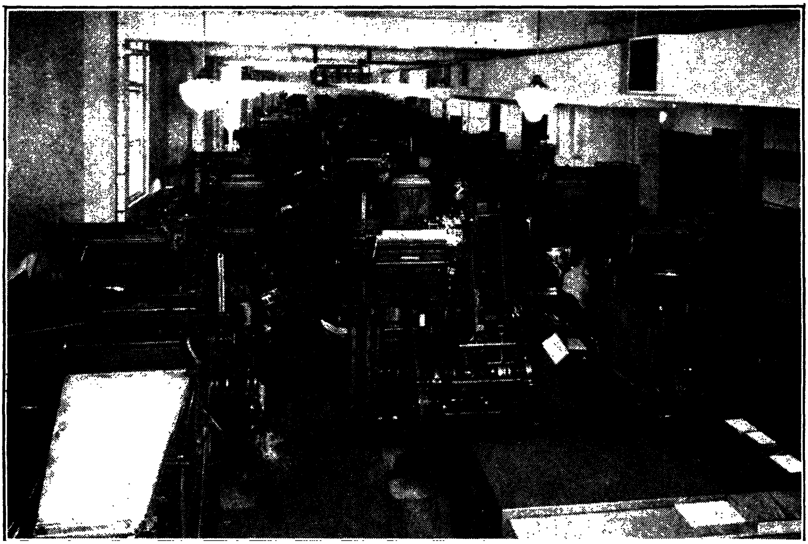


FIGURE 4. General Ventilation in a Printing Plant

changes per hour are not enough for certain conditions requires a down-to-earth calculation on the basis of the amount of material escaping into the air and the maximum allowable concentration of the material.

For example, let us consider the minimum general ventilation rate required for the spray-painting section of an automotive-maintenance garage. The plans prepared by plant or ventilating engineers which have come to the author's attention in recent years indicate that 20 to 30 air changes per hour are considered "ample" to control the spray-painter's exposure. Since the painting section is frequently a partitioned corner or end of the garage having a cubical content in the order of 4500 cu ft, and, since the thinners for many lacquers, paints, and enamels have maximum allowable concentrations of 200 ppm or less,[56] it can be shown by equation 1

given later that a ventilation rate in the order of 7500 cfm (100 air changes per hour) is needed to dilute adequately the vapors from one spray gun when in operation. This assumes perfect dilution between the source of the vapor release and the workers' breathing zone, and, since this condition is seldom realized in practice, a

FIGURE 5. General Ventilation in a Printing Plant

correspondingly higher ventilation rate is needed if the hazard is to be controlled solely by general ventilation.

Volume of Air Needed. General or dilution ventilation is well adapted to the control of relatively nontoxic materials, particularly if the materials are not liberated into the air near workers in highly concentrated form.[57, 58] It follows therefore that the vapors of solvents, solvent cleaners, and solvent thinners may frequently be controlled by this means since most solvents are less toxic than many dusts and fumes (see table 1) and are usually not released at such high rates. The quantity of air needed to dilute a solvent vapor to a harmless level (the maximum allowable concentration) may be com-

puted with considerable accuracy if the rate of solvent consumption is known. Such information can be obtained from the stockroom clerk, the workroom supervisory personnel, or by personal observation and investigation. If maximum or complete dilution of the contaminated air (vapor) between its source and the breathing zone of the worker is accomplished by good air circulation within the room, the required minimum quantity of air for a given room or space may be computed as follows:

$$Q = \frac{0.81 \times 10^6 \times S}{WC} \tag{1}$$

where Q = ventilation rate in cubic feet per minute.
S = rate of solvent consumption in pounds per 8-hour day.
W = gram-molecular weight of the solvent.
C = maximum allowable concentration of the solvent in parts per million (see table 1).

NOTE. It is convenient to remember that the vapors of a gram molecular weight of any solvent will occupy 0.86 cu ft at room temperature and normal pressure.

Since complete dilution of the contaminated air is usually not attained before it reaches the breathing zone of the nearby worker, the ventilation rate must be increased accordingly. The amount to increase it can only be determined by a careful study of all the factors involved, such as circulation rate, distance of worker from source of vapor, importance of heat loss, and number of workers affected. With reasonably good air circulation and with the worker's face at approximately arm's length from the source of the vapor, the constant in the foregoing equation should fall somewhere between 1.2 and 2.0 although it may be higher.

By a similar procedure the required minimum ventilation rate may be computed for dusts or fumes if the production rate is known. Thus

$$Q = \frac{0.033 \times 10^6 \times S}{C} \tag{2}$$

where Q and S are as given in equation 1 and C is the maximum allowable concentration of the contaminant in milligrams per cubic meter (mg/m^3) (see table 1).

Where to Use This Type of Ventilation. General ventilation alone is rarely satisfactory for dust or fume control, as indicated

earlier, owing to the relatively high toxicity of such contaminants and the high rate at which they are often produced. This fact is clearly demonstrated in table 6, which contains data on minimum dilution ventilation rates required to control several different materials at the same rate of release (by weight) into the atmosphere. It is apparent from these data that general ventilation as an atmospheric sanitation measure is limited largely to gaseous contaminants (gases and vapors), except mercury.

TABLE 6

VENTILATION RATES FOR DILUTION

Substance	*Maximum Allowable Concentration*	*Quantity of Air in Cubic Feet per Minute Required to Dilute 1 Lb per Hour of Substance to Safe Level*
Acetone	400–500 ppm	225– 280
Benzol	50–100 ppm	850–1700
Carbon tetrachloride	50–100 ppm	425– 850
Carbon disulfide	20 ppm	4,250
Lead	0.15 mg/m^3	1,790,000
Mercury	0.10 mg/m^3	2,680,000
TNT	1.5 mg/m^3	179,000
Silica	5 mppcf	45,600 *

* Based on 30,000,000 particles per milligram.

Table 7 contains useful data for designing general ventilating systems for a number of volatile solvents frequently encountered in industry. In the right-hand column are given the general ventilation rates in cubic feet per minute required to dilute 1 lb per minute of the solvent to the maximum allowable concentration. These values were computed by the formula given earlier in this chapter, using the maximum allowable concentrations listed in table 1, Chapter I, and assuming complete dilution between the source and the worker's breathing zone. Except in rare instances, these rates must be increased in practice as explained earlier. Some of the substances listed, such as acetone, formaldehyde, and ethyl alcohol, are irritating or otherwise objectionable to some or all of the workers at concentrations below the toxic limit given in table 1. From the strictly engineering viewpoint it is advisable to use lower design concentrations for such chemicals,[59] but many industrial hygiene engineers, particularly those with governmental agencies, might have considerable difficulty in justifying this approach for the time being, at least.

TABLE 7

VENTILATION RATE DESIGN DATA FOR A NUMBER OF COMMON CONTAMINANTS

Substance	*Molecular Weight*	*Specific Gravity*	*Required Minimum Dilution Rate in Cubic Feet per Minute per Pound per Minute*
Acetone	58.08	0.79	12,400
Acetylene tetrachloride	167.86	1.58	231,600
Acrylonitrile	53.06	0.80	366,000
Amyl acetate	130.18	0.87	8,450
Amyl alcohol	88.15	0.82	22,000
Benzol	78.11	0.88	49,800
Butanone	72.10	0.81	25,200
Butyl acetate	116.16	0.88	8,350
Butyl alcohol	74.12	0.81	24,500
Butyl cellosolve	118.17	0.90	16,400
Carbon disulfide	76.13	1.26	255,000
Carbon tetrachloride	153.84	1.58	25,300
Cellosolve	90.12	0.93	21,500
Cellosoive acetate	132.16	0.97	29,400
Chloroform	119.39	1.50	32,500
Cyclohexanol	100.16	0.96	39,200
Cyclohexanone	98.14	0.95	39,600
Dichlorobenzene	147.01	1.32	35,200
Dichloroethylene	96.95	1.25	40,100
Dichloroethyl ether	143.02	1.22	181,200
Dioxane	88.10	1.03	8,820
Ethyl acetate	88.10	0.89	11,000
Ethyl alcohol	46.07	0.81	8,460
Ethylene dichloride	98.97	1.26	39,300
Ethyl ether	74.12	0.72	10,500
Hexanone	100.16	0.80	19,400
Mercury	200.61	13.55	160,000,000
Methyl acetate	74.08	0.94	13,100
Methyl alcohol	32.04	0.79	60,600
Methyl cellosolve	76.09	0.96	51,200
Monochlorobenzene	112.56	1.11	46,100
Naphtha (petroleum)	110	0.75	3,540
Perchloroethylene	165.85	1.62	12,500
Propyl acetate	102.13	0.87	9,540
Propyi alcohol	60.09	0.79	16,200
Solvesso	125	0.80	15,500
Stoddard solvent	130	0.80	3,000
Styrene monomer	104.14	0.91	9,300
Toluol	92.13	0.86	21,100
Trichloroethylene	131.40	1.48	14,800
Turpentine	136	0.87	14,300
Xylol	106.16	0.88	18,400

Tables C and D in the Appendix [56] are also useful as a guide to the composition of many common solvent degreasers, cleaners, and thinners. These analyses were made early in 1945 and in many instances are probably no longer accurate. However, the nature of the ingredients of such products is dictated largely by the job to be done, and the ingredients are, therefore, remarkably similar even though the actual percentages of each type may vary considerably. For control purposes it is desirable for the industrial hygiene chemist or engineer in private industry to obtain similar data on all solvents used by the industry.

Ventilation Rate Terminology. From the viewpoint of atmospheric sanitation, the term "air changes per hour" is practically meaningless; the ventilation rate should be given in cubic feet per minute (cfm) or other absolute terms. Only when considering a given room or building does rate of air change have any significance. Under such conditions increasing the ventilation rate from 15 to 30 air changes per hour would result in reducing the concentration of the atmospheric contaminant to about 50% of its former value. However, for a given operation or rate of dust production the atmospheric concentration will be roughly twice as high in a room $20 \times 20 \times 10$ as in a room twice this size ($40 \times 20 \times 10$) if each is ventilated at the same rate in terms of air changes per hour. In other words, it is the absolute ventilation rate in cubic feet per minute, as shown in equations 1 and 2, which determines whether the control is adequate, and not the air changes per hour.

Density of Contaminant. Another common rule-of-thumb design procedure which is incorrect is the belief that all heavier-than-air gases and vapors must be exhausted at the floor, and gaseous contaminants which are lighter than air must be exhausted at or near the ceiling. Though it is true that some vapors, such as trichloroethylene and carbon tetrachloride, are three or four times as heavy as air, they do not occur in workrooms in concentrated form owing to (1) their low vapor pressure at room or operating temperature and (2) their natural dispersion into the air by molecular and air movement and by vapor pressure. Consequently, instead of concentrated vapor we encounter vapor-in-air mixtures with the vapor concentration seldom exceeding 1% or 10,000 ppm. Even for heavy vapors, such as carbon tetrachloride, a 1%-in-air mixture weighs only about 4% more than air. Such mixture obviously will not settle with great rapidity nor will it interfere significantly with ceiling exhaust if such ventilation is indicated by other and more

important considerations. Of greater importance by far is the relation of the source of contamination to the worker's face. If the vapor or gas is released into the air below the worker's face, down draft is indicated, and vice versa. The supply and/or exhaust should be so located that the worker is on the upwind or clean-air side of the operation as much as possible.

General vs. Local Exhaust. There is no hard and fast distinction between some general exhaust ventilating systems and local exhaust systems. If the exhaust terminal (suction opening) of a general ventilating system is located near a source, or in an area, of excessive contamination, it accomplishes both local exhaust and general ventilation. In fact, practically all local exhaust systems are also general ventilating systems. As a rule, however, the better designed and the more efficient they are as local exhaust systems, the less will be the general ventilation rate produced. Probably the best criterion as to whether a given system is one of local exhaust or general ventilation is the atmospheric concentration of the contaminant in the exhaust duct as compared with that in the general room air. If the concentration of the contaminant in the exhaust duct air is not significantly higher than in the general room air the system is one of general ventilation. If the contaminant concentration in the exhaust duct is much higher than in the general room air it is primarily a local exhaust system but may also be secondarily a general ventilating system. For example, the hood attached to a flexible metal duct for welding and for granite surfacing, and the hoods at grinding machines, are parts of local exhaust systems. On the other hand, most plating- and degreasing-tank ventilation is primarily local exhaust but accomplishes considerable dilution ventilation also. This becomes apparent, as is demonstrated elsewhere in this book, when one reflects a few minutes on the extremely low rate of local exhaust ventilation required for such tanks —a rate plainly too low to act effectively through local exhaust alone.

Supply or Exhaust. There is no "cook-book" procedure for determining whether a general ventilating system should be supply only, exhaust only, or a combination of both. Each problem must be studied carefully to obtain the best arrangement. However, consideration of the following pointers will aid in arriving at a satisfactory solution:

1. The exhausted air must be replaced, either by a supply system or by providing easy entrance for the make-up air.

2. Provision must be made to heat make-up air in cold weather.

3. Short-circuiting of air must be prevented; as much as possible of the air should pass through the zone or over the sources of contamination.

4. If exhaust only is used, cold drafts near doors and windows must be prevented.

5. As a rule, better dilution and lower operator exposure are accomplished with a well-designed supply system than with exhaust, since the supply air can be directed toward the important sources of contamination, and good circulation is effected without accessory equipment.

6. A combined supply and exhaust system is preferred with a slight excess of exhaust if there are adjoining occupied spaces and a slight excess of supply if there are no such spaces.

7. The ventilation rate produced by a combination of supply and exhaust is not the sum of both; it is the rate of the one having the greater capacity.

8. Supply alone will contaminate the air of adjoining occupied spaces.

9. Drafts from make-up air must be prevented, particularly near supply inlets. Recommended maximum inlet velocities for air not more than 10° F below the general room temperature are: [60]

120 fpm for inlets less than 8 ft above floor.
250 fpm for inlets 8–12 ft above floor.
500 fpm for inlets 12–18 ft above floor.
1000 fpm for inlets more than 18 ft above floor.

10. Air velocities from supply inlets or the location of the supply must not be such as to disturb the air flow at local exhaust hoods.

Even though general ventilation is satisfactory for most solvent exposures, it is unwise to resort to this control method if the contamination sources are more or less definite. Local exhaust ventilation will be more effective and will require much less air movement resulting in less heat loss for the same degree of control. On the other hand, general ventilation is particularly well suited to control minor and scattered sources of contamination.

The calculations of pressure losses and duct sizes and for fan selection are similar to those for local exhaust systems. Since these are covered in detail in Chapter VI, they will not be included here

CHAPTER V

LOCAL EXHAUST VENTILATION—HOOD DESIGN

As indicated in Chapter III, local exhaust ventilation is the most important single method of preventing industrial atmospheric pollution. Yet the fundamental principles involved in the proper design of local exhaust systems are understood thoroughly by only a small number of people with the result that (1) this control measure is not used as widely as it should be, and (2) many of the systems being installed even today are unsatisfactory. This has a distinctly unfavorable influence on the national industrial atmospheric sanitation program because management is not willing to be "stung twice in the same place."

Local exhaust systems are sometimes called process ventilating systems. Neither of these terms is wholly satisfactory nor does a truly descriptive expression appear in the literature. They have been termed local exhaust systems because in construction and appearance aspects they are similar to other exhaust ventilating systems except that the point of operation is specific or local. However, terminology is not too important as long as the industrial hygiene engineer and other engineers engaged in atmospheric sanitation engineering appreciate thoroughly how these systems function so that they can design them properly.

From the functional viewpoint local exhaust systems are more like sewerage systems than like ventilating systems. They are intended to collect the contaminated air in as concentrated form as possible and convey it to suitable disposal equipment and/or locations. Though the object of such systems is to prevent dusts, fumes, smokes, mists, gases, and vapors from getting into the general workroom air in harmful proportions, it must be kept firmly in mind that technically speaking they do not remove these contaminants from the air, *they confine and remove the contaminated air.* All contaminants escape into the air immediately surrounding the source of contamination, and it is this air with the contaminant in highly concentrated form which local exhaust systems are intended to col-

lect to prevent it from mixing with the general workroom air and making it unfit for human consumption.

Contaminant Dispersion. Before considering the design of local exhaust systems it is necessary to study the ways by which the contaminants are produced or released. Dusts, fumes, smokes, and mists (particulate matter), if of large particle size and if thrown off with high velocity, will be dispersed by their own kinetic energy. However, most large particles settle rapidly in relatively still air and are usually of secondary importance as a factor in the causation of occupational diseases (see Figure I in the Appendix). Microscopic particles, on the other hand, can be dispersed only very little distance by virtue of their own kinetic energy. They are dispersed primarily by air movement. Vapors and gases are dispersed by diffusion, density difference, and air movement. Of these, air movement is probably of primary importance although diffusion may be of considerable influence under certain circumstances. Density difference is seldom of great importance except in very still air, as shown in the preceding chapter. Consequently, it becomes obvious that *local exhaust systems must act largely by controlling the motion of the contaminated air.*

Air-Motion Control. The air motion around hazardous operations and processes may result from (1) the operation of the machine or process itself, such as the fan action of a rotating wheel, the escape of air from containers as they are filled, vibration of machinery, escape of air past worn pistons, and the drag of air by large particles thrown off at considerable velocity; and (2) external forces, such as open doors and windows, inlet supply ports, movement of nearby workers and machinery, and temperature differences. This air motion must be brought under control by eliminating the sources, if possible, or by reducing the velocity of the air motion as much as possible and then bringing it under the influence of the local exhaust hood.

HOOD DESIGN

It has been stated frequently that the hood is the most important part of an exhaust system. Since the effectiveness of a hood depends upon the connecting duct and the exhauster as well as upon the shape of the hood, the author prefers to think that it is the most critical rather than most important part of the system. It is the function of the hood to enclose the sources of contamination as

completely as possible and/or to create an air-flow pattern at the point (or in the area) of contaminant escape of such velocity and direction as to capture the grossly contaminated air and convey it into the local exhaust system. The object of hood design is, therefore, to prevent the escape of excessive amounts of the grossly contaminated air into the general room air with a minimum amount of interference with the performance of the operation and with a minimum rate of air flow into the hood.

Hood design is quite difficult except in those instances where the engineer has previously designed hoods which have been shown to be satisfactory for similar operations. For new or dissimilar operations the design of an efficient hood involves a number of considerations which are embodied in the following six steps:

1. Study of the process or operation.
2. Selection of minimum control velocity (or air volume).
3. Study of equipment and structure surrounding the operation.
4. Selection of the best type of hood.
5. Determination of the volume of air which must be exhausted.
6. Development of hood shape and size.

Study of the Process or Operation. Most operations or processes vary sufficiently one from the other so that each requires individual consideration if a reasonably satisfactory control system is to be obtained. Some operations disperse dusts or mists at a high velocity in a more or less definite direction, others in all directions, and some release the material without any significant initial velocity. At some operations there is considerable air disturbance caused by nearby open doors or windows or by rapidly moving machinery; at others there is no significant disturbance. At some operations the specific gravity of the contaminated air is sufficiently different from the room air to require consideration; in others the temperature difference is of primary importance.

Selection of Minimum Control Velocity. Here experience is a great asset; however, often a satisfactory minimum control velocity can be selected by using table 8 as a guide. The minimum control velocity is the air velocity which must be created by the local exhaust hood at the source (or over the area) of contaminant release to capture a sufficiently large percentage of the contaminant to prevent the creation of a health hazard. A health hazard will exist if the concentration of the contaminant in the air breathed by the nearby workers exceeds the maximum allowable concentration.

Control velocity is of primary importance when considering small hoods involving low quantities of air flow. For large hoods and rates of air flow, general or dilution ventilation frequently is more important than the local exhaust effect, as explained later, and control velocities, as such, play a secondary role. Also the depth of the control air stream plays a most important part in the capture

TABLE 8

MINIMUM CONTROL VELOCITIES

(Minimum air velocities recommended for the capture of dusts, fumes, smokes, mists, gases, and vapors released at various types of operations)

Conditions of Generation, Dispersion, or Release of Contaminant	*Minimum Control Velocity (feet per minute)*	*Example of Processes or Operations*
Released with no significant velocity into relatively quiet air	100	Evaporation or escape of vapors, gases, or fumes from open vessels; degreasing; pickling; plating
Released with low initial velocity into moderately quiet air	100– 200	Spray-paint booths, cabinets, and rooms; intermittent dumping of dry materials into containers; welding
Released with considerable velocity or into zone of rapid air movement	200– 500	Some spray painting in small booths and with high pressure; active barrel or container filling; conveyor loading
Released with high velocity or into zone of very rapid air movement	500–2000	Grinding; abrasive blasting; surfacing operations on rock

of the contaminated air. The capturing power of an air stream into an exhaust hood is a function of *the product of the velocity and the distance through which it acts,* not of the velocity alone. Obviously, a dust particle or a unit volume of contaminated air traveling away from an exhaust hood by virtue of momentum imparted to it by a machine will not continue indefinitely in that direction against a counterflow of air even though it might readily continue through the small "defense depth" set up by a small hood. The effective defense depth of a small hood (and some enclosing hoods) is only a matter of a very few inches owing to the rapid decrease of V as the distance from the hood increases. In large hoods or hoods involving large quantities of air flow, such as are used at foundry shakeout operations, pickling, plating, and degreasing tanks, and for

spray painting, the capturing air velocity remains effective for a considerable distance or depth. This "defense-in-depth" factor changes the entire concept of the value of minimum or critical control velocities.

It must be borne firmly in mind, therefore, that control velocities as given in table 8 are only guides. The actual control factor is a function of the velocity of air flow multiplied by the distance through which the velocity acts. Therefore, since *large exhaust hoods* accomplish considerable control by means of general ventilation in addition to unusually effective local exhaust control through "defense in depth," they *will very frequently control the hazard satisfactorily with considerably less air flow* than estimated by the equations given later in this chapter. The extent of our knowledge on this particular subject today does not permit an accurate solution of such problems. Experience with similar problems, or experimental hoods, provide the only satisfactory solution apparent at this time. Some research is in progress on this phase of industrial hygiene engineering but much more is needed to change it from an art to a science.

The use of table 8 as a guide by the inexperienced engineer may frequently result in inadequate control by small hoods unless the designer bears firmly in mind that most control velocities are very low and can be nullified by drafts or nearby moving machinery. For example, the average person walks at the rate of 350 fpm. Consequently, a worker or piece of equipment, such as a crane- or motor-operated lift truck, may create an air movement in excess of 100 fpm at nearby operations. On the other hand, an overdesigned system and unnecessary heat loss will result if the minimum control velocity is selected to meet all contingencies. A certain amount of atmospheric contamination can be tolerated by the average worker without any demonstrable ill effects. Therefore, it is permissible to allow some contaminant to escape, and, in those instances where the air-flow pattern created by the hood is upset infrequently for momentary periods, no harm will result as a rule. Only if the interference is frequent or continuous and cannot be eliminated by baffles or partitions, is it necessary to select a minimum control velocity which will overcome the interference.

Sometimes the required minimum control velocity or quantity of air exhausted can be determined by direct measurement of the air velocity into other exhaust hoods which are operating satisfactorily at similar operations. In other instances it is advisable, and eco-

nomically feasible in the long run, to experiment with full-scale model hoods. The process is isolated from other sources of contamination and the volume of air required to obtain satisfactory conditions (on the basis of the atmospheric contaminant concentration) is determined.

Study of Equipment and Structure Surrounding the Operation. This step is a prerequisite to accomplishing steps 4 and 6. It is necessary that the engineer have data regarding the location or area of the contaminant release, the movements of the workers, and the location of other equipment. He may then design a hood which will produce the necessary control velocity or dilution rate at the source (or over the area) of contaminant release with the least amount of air flow and with a minimum of interference with the normal movement of the operators. Also, he must have plans of the building and of the location of other equipment, in order to design the ductwork.

Selection of the Best Type of Hood. Steps 1 and 3 provide the information needed to select the type and to determine the hood location. Detailed information on types of hoods is given later under "Air Flow vs. Hood Shape." It is necessary that the velocity patterns in front of different types of suction openings be understood clearly if the best hood is to be selected.

In addition to knowing what types of hood to select, it is imperative that (*a*) the hood be located as near to the source of contamination as possible, or enclose it; (*b*) the hood be located in the "direction of throw" of the contaminant if possible; (*c*) it not interfere excessively with the proper conduct of the operation; (*d*) due consideration be given to the use of baffles and flanges to prevent disturbance of the air pattern in front of the hood, in order to stop flying particles or to deflect them into the hood; and (*e*) due consideration be given to the influence of differences in temperature and specific gravity between the contaminated air in the zone of contaminant release and the general room air.

Determination of Air Volume to Be Exhausted. The engineer now has a mental picture of the operation and of the hood shape and location. The next step is to estimate the quantity (Q) of air which must be exhausted to capture the contaminant. Equations and charts discussed under "Air Flow vs. Hood Shape," and table 8, cited previously, enable the designer to determine Q very conveniently.

Development of Hood Shape and Size. From information obtained in the first five steps in the design, the engineer can develop the approximate hood-layout plans with dimensions except for the exact size of the branch duct connection which will be determined later. Considerable saving in ultimate power consumption can be effected if the hoods are streamlined as much as practicable; abrupt velocity changes and direction changes are to be avoided. The means of shaping the hoods to keep the energy losses at a minimum is indicated briefly later in this chapter under "Streamlining Hoods," and in the following chapter under "Hood Loss."

Air Flow vs. Hood Shape. For this discussion, all hoods may be divided conveniently into four major groups.

1. Enclosing hoods.
2. Rectangular or round hoods.
3. Slot hoods.
4. Canopy hoods.

Though there is considerable overlapping or duplication in the foregoing grouping the distinction will become clear from the following discussion.

Enclosing Hoods. Contamination sources should be wholly or partially enclosed whenever possible. Enclosing hoods are more efficient than other types since the ineffective areas are closed off, and disturbance by extraneous air currents is kept to a minimum. Examples of enclosing hoods are spray-paint booths, laboratory hoods, luminous-dial-painting hoods, abrasive-blasting cabinets, some grinder hoods, and some shakeout hoods.

Since the function of any exhaust hood is to create air movement of the proper magnitude and in the proper direction to capture the contaminant, it is obvious that adequate control will be accomplished if the minimum control velocity is created through all the openings in the enclosing hood. Hence it is apparent that the following equation may be used to determine the quantity of air which must be exhausted from enclosing hoods:

$$Q = AV \tag{3}$$

where Q = the quantity of air in cubic feet per minute.
A = the total area in square feet of the openings into the hood.
$V \doteq$ the minimum control velocity in feet per minute (use table 8 as a guide).

Equation 3 shows at a glance that the required rate of air movement through the hood will be a minimum when the area of the

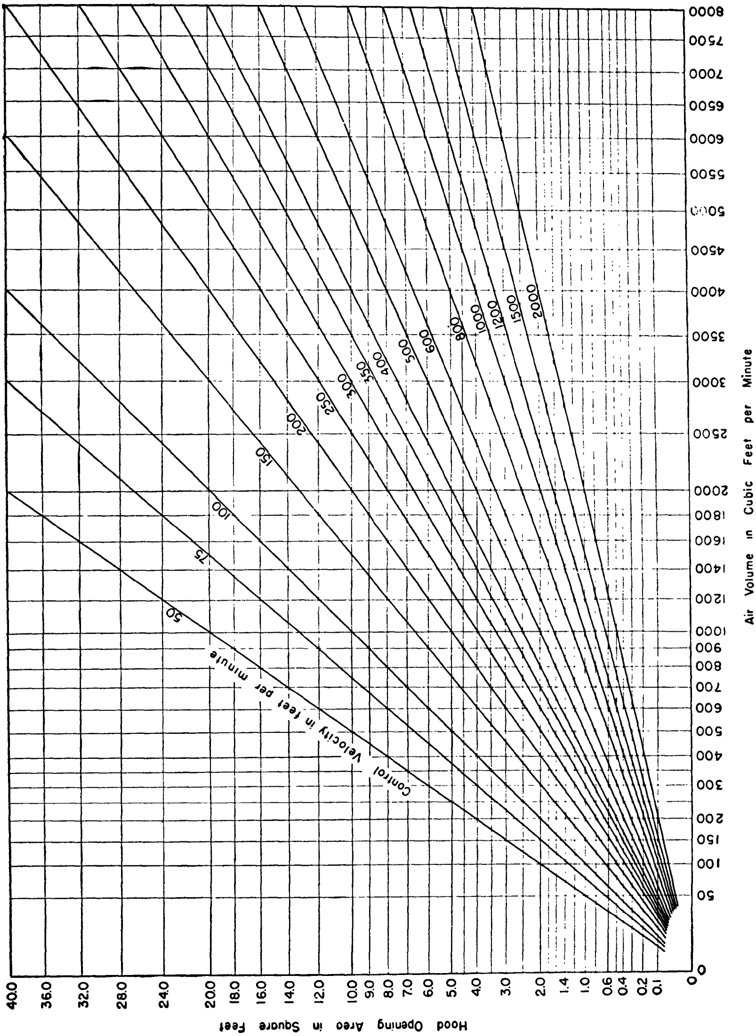


FIGURE 6. Control Velocity, Air Volume, Hood Opening Area Relationship

openings into the hood is as small as is consistent with good performance of the operation or flow of materials.

The required ventilation rate for enclosing hoods for all conditions commonly encountered in industry may be conveniently read

directly from figure 6 if the area of hood openings and minimum control velocity are known.

Enclosing hoods as a group are the easiest to design and if carefully planned have a better chance of satisfactory performance than other types of hoods. For this reason, and owing to their high efficiency and positive action, they should be used wherever possible.

Rectangular or Round Hoods. These hoods are used at operations or locations, such as welding; stone surfacing; downdraft in table tops for degreasing, cleaning, and cementing; drilling; and material transfer. They are the most inefficient type of hoods, as will be shown later, since in most applications a large percentage of the air entering the hood does not pass by the source or through the zone of contamination.

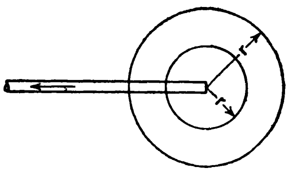


FIGURE 7. Velocity Contours Around a Hypothetical Point Source of Suction

To understand fully the shape of the air velocity pattern in front of rectangular or round exhaust hoods, it is necessary to visualize a hypothetical point source of suction (figure 7). Under such conditions air would enter the suction point equally from all directions, and the velocity contours would be spherical surfaces having their centers at the suction point. The total quantity of air entering the point source of suction could be determined if the air velocity were measured at any point x distance from the suction point, by the equation for the flow of fluids, namely,

$$Q = AV \tag{4}$$

where Q = the quantity of air in cubic feet per minute.

A = the area in square feet of the surface of the sphere having a radius of x ft.

V = the air velocity in feet per minute at x distance from the suction point.

Since A is a spherical surface it is equal to $4\pi r^2$ (that is, $4\pi x^2$), which is equal to $12.57x^2$. Hence equation 4 becomes $Q = 12.57x^2V$, which we shall write as $Q = V(12.57x^2)$ for comparison with equation 5, which will follow shortly.

Obviously, the air-flow pattern created by a freely suspended round or rectangular exhaust hood does not conform strictly to the

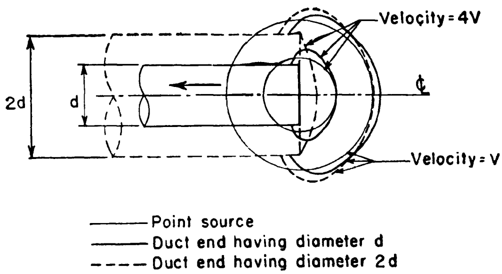


FIGURE 8. Velocity-Contour Comparison for Point Source and Plain Duct Ends (Q remains constant)

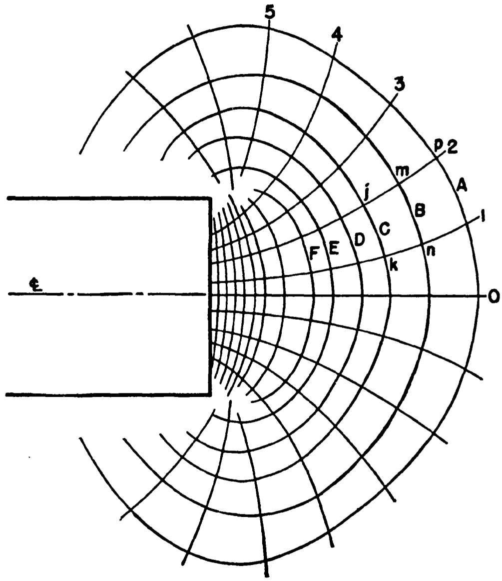


FIGURE 9. Velocity Contours for Circular Duct End under Suction (*Courtesy Dalla Valle*)

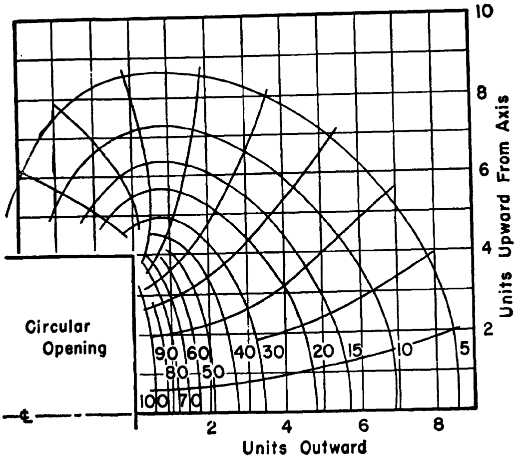


FIGURE 10. Velocity of Contours in Percentage of Face Velocity for Circular Suction Openings (*Courtesy Dalla Valle*)

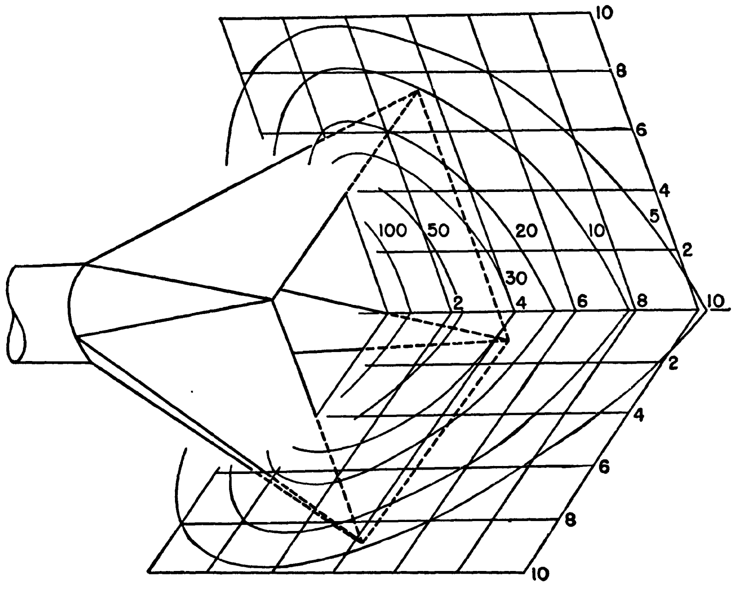


FIGURE 11. Velocity Contours in Percentage of Face Velocity for Square Suction Openings (*Courtesy Dalla Valle*)

hypothetical point source of suction (see figures 8 to 15). The contour shape was found by experiment to change slightly and to flatten directly in front of the hood as shown in the figures. By studying

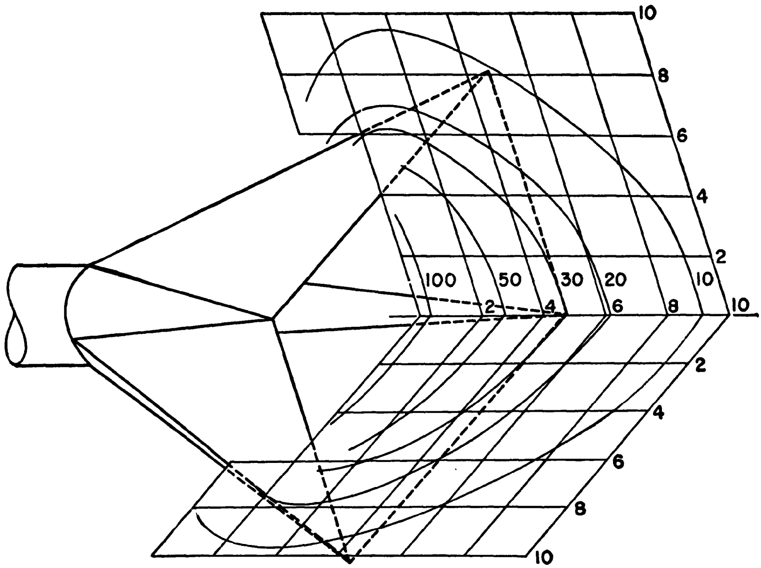


FIGURE 12. Velocity Contours in Percentage of Face Velocity for Rectangular Suction Openings Having Sides Ratio of 3 to 4 (*Courtesy Dalla Valle*)

the air-flow characteristics of freely suspended round and rectangular hoods, Dalla Valle found that the centerline air-flow relationship may be expressed by the following equation: [61]

$$Q = V(10x^2 + a) \tag{5}$$

where Q = quantity of air exhausted in cubic feet per minute.
V = air velocity in feet per minute at x distance in feet from the hood and on the centerline of the hood.
x = distance in feet along the hood centerline from the face of the hood to the point where the air velocity is V feet per minute.
a = area in square feet of the hood opening.

Other equations for the centerline air-flow relationship in front of suction openings have been reported,[62] but field tests and recent

laboratory studies[63] indicate that equation 5 expresses this relationship more nearly accurately. Consequently, it is adhered to throughout in this book.

In his comprehensive study of air flow into suction hoods Dalla Valle[61] discovered the principle of "similarity of contours." The principle may be stated as follows: "The positions of the velocity

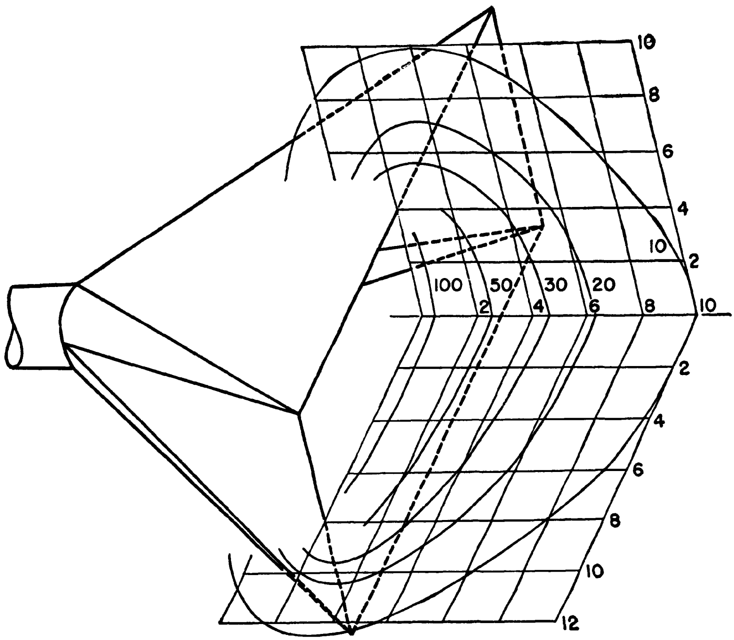


FIGURE 13. Velocity Contours in Percentage of Face Velocity for Rectangular Suction Openings Having Sides Ratio of 1 to 2 (*Courtesy Dalla Valle*)

contours for any hood when the contours are expressed in terms of the average velocity at the hood opening are purely functions of the shape of the hood; the contours are identical for similar hood shapes when such hoods are reduced to the same base of comparison." This principle is well illustrated in figures 9 to 15 which were taken from reference 25. It serves as a most useful tool in hood design since large hoods may be tested in model form and the air-flow characteristics developed from the small hoods, as long as all dimensions are kept to proper scale. Likewise, it is invaluable to the industrial health engineer since, if he understands the nature

of air flow into a few representative hoods, he can develop the contours for large similarly shaped hoods very easily. (NOTE. There is some doubt as to the accuracy of the principle of "similarity of contours" for hoods of widely different sizes, owing to the changing ratio of the hood face area to its perimeter. However, the principle is sufficiently accurate for all practical purposes.)

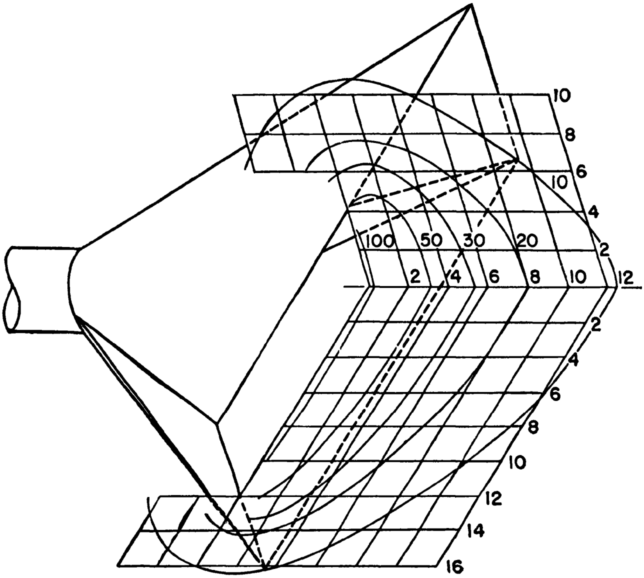


FIGURE 14. Velocity Contours in Percentage of Face Velocity for Rectangular Suction Openings Having Sides Ratio 1 to 3 (*Courtesy Dalla Valle*)

It should be noted that equation 4 defining the air-flow relationship into a hypothetical point source of suction is almost the same as equation 5, which gives the centerline air-flow relationship for round or rectangular hoods, particularly if the hoods are small, since a then becomes relatively unimportant.

It must be borne in mind, of course, that equation 5 expresses the centerline or axial velocity, not the velocity at any point in front of such hoods. However, the contours in front of freely suspended round or rectangular hoods are of such shape that this equation may be used to determine with sufficient accuracy the velocity at any point in front of the hood. To do this, x should be measured in feet from the center of the plane of the hood opening for points

at a relatively large distance from relatively small hoods (see figure 16). For conditions where the source or area of contamination is at a relatively short distance from a relatively large hood,

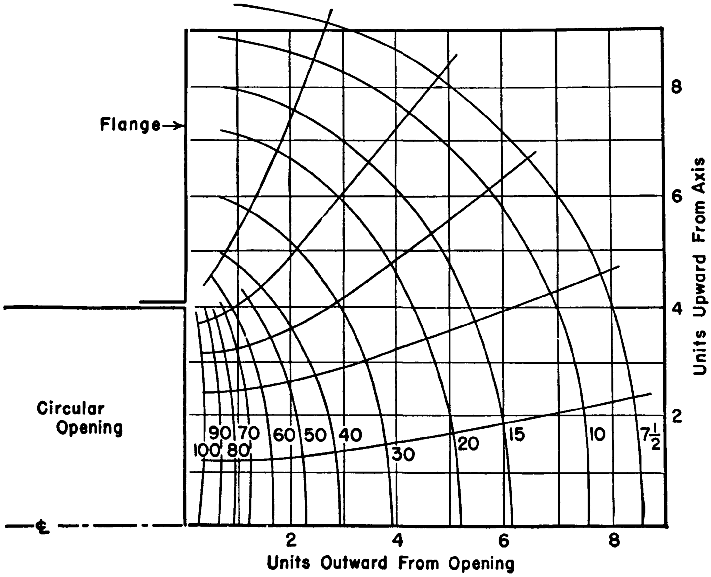


FIGURE 15. Velocity Contours in Percentage of Face Velocity for Flanged Circular Openings (*Courtesy Dalla Valle*

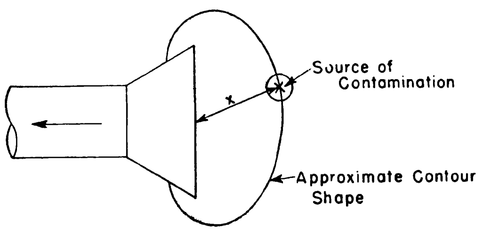


FIGURE 16. Determining x under Conditions Where Hood Area Is Relatively Small and x Is Relatively Large

x should be measured perpendicular to the plane of the hood opening except that it should not be measured from a point in the plane of the hood opening which is closer to the edge of the hood than twice the perpendicular dimension to the source or area of con-

tamination (see figure 17). This procedure gives reliable data, particularly to the experienced engineer, and dispenses with the more cumbersome procedure of first plotting the approximate contours in front of the hood and then determining Q.[64]

For convenience, these calculations are accomplished in figures 18 and 19 so that Q may be read directly after V, x, and a have been determined as discussed earlier under steps 1, 2, 3, and 4. In figure 18 the hood area in square feet and the value of x in inches are used to obtain a dimensionless reference value called the "hood-location

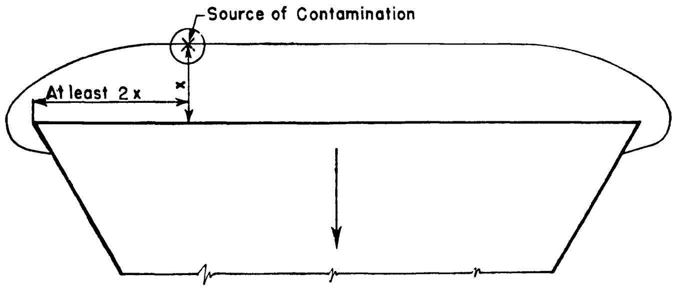


FIGURE 17. Determining x under Conditions Where Hood Area Is Relatively Large and x Is Relatively Small

function." For circular hood openings, such as duct ends, the area a need not be determined; reference can be made to the duct diameter directly, as shown at the top and to the left of figure 18. Using the "hood-location function" and V, the value of Q may be read directly from figure 19.

For example, determine the quantity of air which must be exhausted through a plain end flexible metal tube 4 in. in diameter to create a control velocity of 100 fpm at a welding operation which is never more than 9 in. away from the duct end. In figure 18, the 4-in. diameter line and the 9-in. distance line intersect at a hood-location-function value of about 5.7. In figure 19 the intersection of the 100-fpm-velocity line and the 5.7-hood-location-function line is at a value of about 570 cfm, which is the value of Q. It must be borne in mind, however, that this value applies only to a freely suspended hood. If the end of the duct rests on a table top, some of the ineffective area is cut off and the value determined by equation 5 or by figures 18 and 19 may be reduced about 25%. Likewise, if a flange is used around the edge of the duct, some of the ineffective area will be cut off, and the quantity of air

needed to obtain the desired control velocity is decreased about 20%. Hence, if the operation is conducted on a table top and there

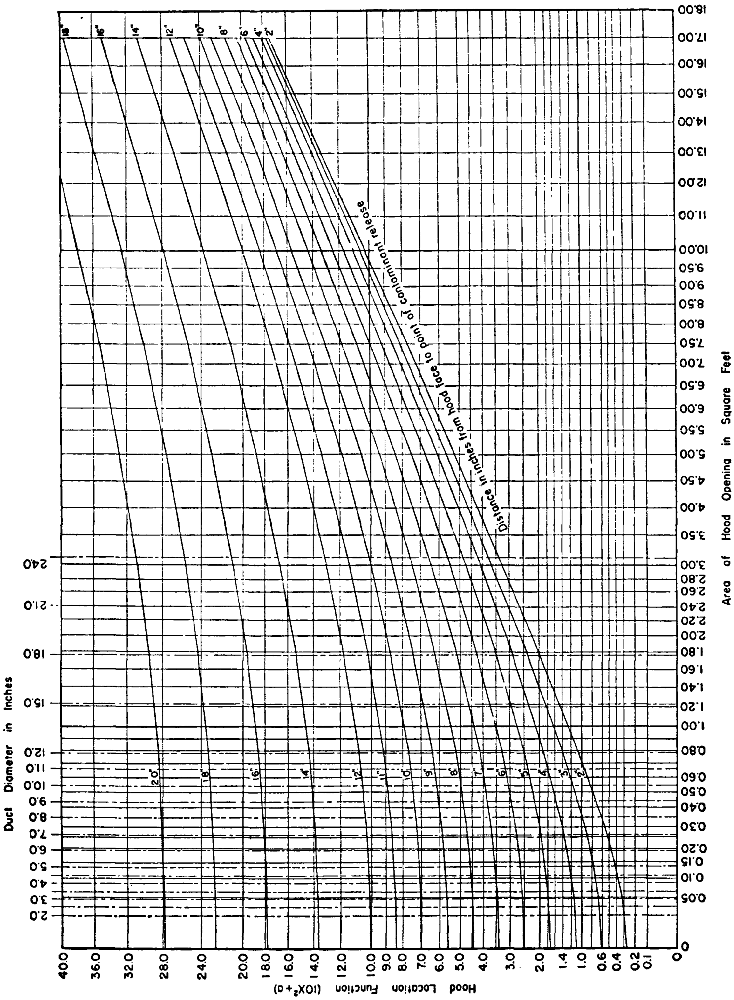


FIGURE 18. Hood Area, Hood Location, Hood Location Function Relationship

is a 4-in. or 6-in. flange around the pipe end, the required exhaust rate is $570 - (143 + 85) = 342$ cfm.

The quantity of air required to create a control velocity of 200 fpm at several different distances from hoods of different areas has been calculated and is listed in table 9 for the convenience of those

who prefer tables to graphs. For control velocities other than 200 fpm, the correct value of Q may be calculated by multiplying the

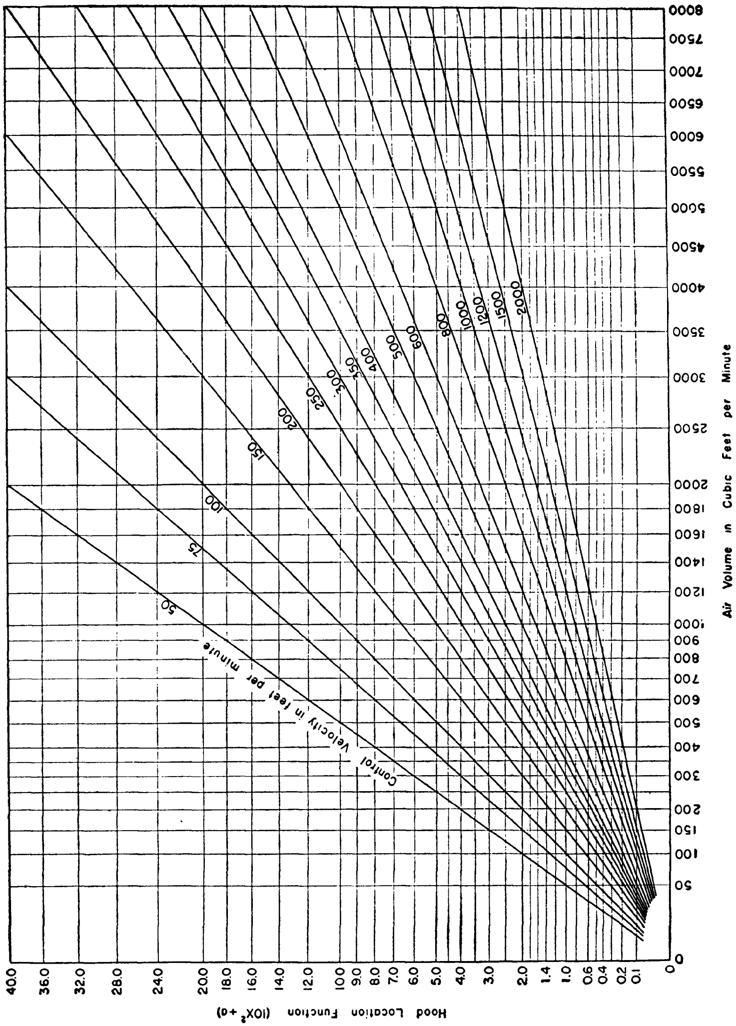


FIGURE 19. Control Velocity, Air Volume, Hood Location Function Relationship

value selected from the table by the ratio of the desired control velocity to 200. Also the values given in table 9 are for freely suspended unflanged hoods. If one edge of the hood is adjacent to a large flat surface the table value for Q should be decreased by about

25%, and if the hood is completely flanged the table value should be decreased about 20%.

TABLE 9

RATE OF AIR FLOW THROUGH DIFFERENT HOOD SIZES TO PRODUCE 200 FPM AT DIFFERENT DISTANCES FROM HOODS

$$[Q = V(10x^2 + a)]$$

Hood Area	*Q in Cubic Feet per Minute for These Distances from Hoods*										
	0	2 in.	3 in.	4 in.	6 in.	8 in.	10 in.	12 in.	15 in.	18 in.	24 in.
7.1 sq in. (3 in. diameter)	10	66	135	230	510						
12.5 sq in. (4 in. diameter)	17	73	140	240	520	905					
24 sq in.	33	89	160	255	535	925	1420				
28.2 sq in. (6 in. diameter)	39	95	165	260	540	930	1430				
36 sq in.	50	105	175	270	550	940	1440	2050			
48 sq in.	67	120	190	290	565	955	1455	2065	3190		
50.3 sq in. (8 in. diameter)	70	125	195	290	570	960	1460	2070	3195		
60 sq in.	84	140	210	305	585	975	1470	2085	3210		
63.6 sq in. (9 in. diameter)	89	145	215	310	590	980	1480	2090	3215	4590	
72 sq in.	100	155	225	320	600	990	1490	2100	3225	4600	
78.5 sq in. (10 in. diameter)	110	165	235	330	610	1000	1495	2110	3235	4610	8110
84 sq in.	115	170	240	340	615	1005	1505	2115	3240	4615	8115
96 sq in.	135	190	260	355	635	1025	1520	2135	3260	4635	8135
120 sq in.	165	220	290	390	665	1055	1550	2165	3290	4665	8165
1 sq ft	200	255	325	420	700	1090	1590	2200	3325	4700	8200
1.25 sq ft	250	305	375	470	750	1140	1640	2250	3375	4750	8250
1.5 sq ft	300	355	425	520	800	1190	1690	2300	3425	4800	8300
1.75 sq ft	350	405	475	570	850	1240	1740	2350	3475	4850	8350
2.0 sq ft	400	455	525	620	900	1290	1790	2400	3525	4900	8400
2.5 sq ft	500	555	625	720	1000	1390	1890	2500	3625	5000	8500
3.0 sq ft	600	655	725	820	1100	1490	1990	2600	3725	5100	8600
4.0 sq ft	800	855	925	1020	1300	1690	2190	2800	3925	5300	8800

From equation 5, it is apparent that Q increases almost as the distance x squared and that V varies directly with Q irrespective of the hood-face velocity. Consequently, the importance of locating hoods of this type as close as possible to the source of contamination is obvious. Also, it is readily apparent that the only way to increase V at a definite distance in front of a given hood is by increasing Q. Yet it is a not infrequent practice of plant engineers to attempt to improve the control effected by local exhaust hoods by increasing the hood velocity through decreasing the size of the hood opening. This does no good except very close to the hood and may even decrease the hood's effectiveness by decreasing Q through increased hood resistance. Whenever the control effected by a local exhaust hood is not adequate it should be improved by one or more than one of the following changes, which are listed in the order of their preference:

1. Move hood closer to source of contamination.
2. Change hood shape or add flanges, or both.
3. Increase Q.

A study of equation 5 shows that for a constant Q, V varies inversely as the hood-location-function value. Consequently, it is apparent from figure 18 that, in general, a small hood opening gives slightly better results than a larger one. This advantage is usually offset by the increased pressure loss at the hood entrance, unless a flange is used at the smaller hood. Even though the entrance loss at a flanged duct end is greater than at a tapered hood of the same functional dimensions, the velocity pattern at the flanged duct end is better than at the tapered hood so that the over-all design is better in some instances (see figure 20).

On the other hand, at those operations where the contaminant is released over a considerable area it is advisable to have a large hood opening so that relatively flat velocity contours are created over the entire area rather than to have a high contour over part of the area and ineffective control near the edges of the area of contaminant release.

Slot Hoods. These hoods are recommended for lateral exhaust ventilation at tanks or vessels, such as those used for degreasing, pickling, and plating; and at table tops or on flat surfaces where the contaminant is released over a considerable area.

Slot hoods are really an extreme form of rectangular hoods. The hood opening is relatively very long (up to 50 ft or more) and relatively very narrow (usually 4 in. or less). However, the air-flow pattern into slot hoods as commonly found in industry is quite different from that into the more conventional form of rectangular hood, and it is for this reason primarily that the two are classified in separate groups.

To obtain a clear picture of the nature of air flow into slot-type suction openings, it is necessary to visualize a line source of suction of infinite length (see figure 21). The velocity contours are obviously cylindrical surfaces with the line source of suction as the axis. Here again, the fundamental equation for the flow of fluids applies, but A is the area of the surface of the cylinder or $2\pi rL$. Hence, equation 4 becomes

$$Q = 6.28rLV \tag{6}$$

where Q = rate of air flow in cubic feet per minute.
r = radius of cylinder in feet, or distance from source of suction to point where air velocity is V.
L = length of cylinder in feet.
V = air velocity in feet per minute at distance r ft from source of suction.

Slot hoods in practice are not infinite in length, and air does not enter uniformly from all directions. Nevertheless, where the length of the hood is great in comparison to the radius of the cylinder or the distance of the hood from the remotest source of contamination, the contours are very flat in the axial plane of the hood, except at the ends (see figure 22). Also, while the contour surfaces are not cylinders they approximate cylindrical surfaces but are only portions (sectors) thereof depending upon the conditions under which the hoods are used. For example, a slot hood adjacent to a table top with a flange extending vertically is drawing air from only about one-quarter of a cylinder. Hence, for slot hoods in general the following equation applies:

$$Q = kLWV \tag{7}$$

where Q = rate of air flow in cubic feet per minute.
k = constant varying from about 1.5 to 5.0 as will be explained later.
L = length of hood in feet.
W = table or tank width in feet (distance from hood to remotest source of contamination—same as r in equation (6).
V = control velocity in feet per minute.

If the contours around a freely suspended slot hood were true cylinders, k would be about 6.28 as shown in equation 6, but they are not. Studies made independently by different workers on the nature of air flow into slot-type exhaust hoods as used at tanks or table tops indicate that the value of k should be about 2.8.[65, 66, 67] Consideration of equation 6 and the nature of air flow into hoods at tanks or table tops indicates that this value is about as would have been predicted since air enters the slot through an effective arc of about 180°.

As indicated previously, k will have a value of approximately 1.5 if the hood has flanges or other restricting surfaces at right angles to each other so that air can enter from only one quadrant.

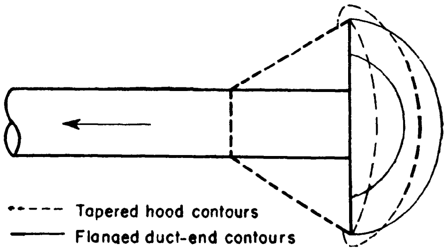


FIGURE 20. Comparison of Velocity Contours at Flanged Duct End and at Tapered Hood of Same Functional Dimensions

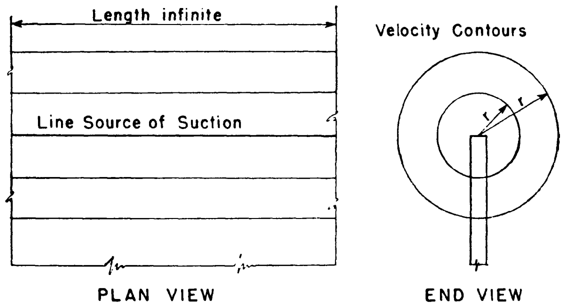


FIGURE 21. Velocity Contours Around a Hypothetical Line Source of Suction

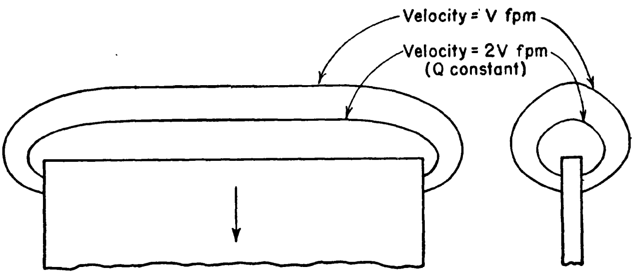


FIGURE 22. Approximate Shape of Velocity Contours in Front of a Freely Suspended Slot Exhaust Hood

In figure 23 these data are plotted so that Q can be read direct if the table or tank dimensions are known. The three curves in the figure cover the usual conditions under which slot-type hoods are used. Also, an arbitrary control velocity of 100 fpm is automatically included in this figure. The first curve ($Q = 150LW$) applies to slot hoods when used adjacent to a large flat surface such as a table top and when the hood has a wide flange at right angles to the flat surface. The second curve ($Q = 280LW$) applies for similar conditions except without the flange. The third curve ($Q = 500LW$) should be used for freely suspended slot hoods without flanges. Where a control velocity other than 100 fpm is needed the value of Q as read from figure 23 must be changed proportionately.

In table 10 are listed the values of Q which will produce a control velocity of 100 fpm at several distances from the slot for tanks or tables of different lengths. For operations requiring control velocities other than 100 fpm, the correct Q may be calculated by multiplying the table value by the ratio of the desired control velocity to 100. The data in the table are based on a value of 2.8 for k—the usual conditions. If the slot hood has a wide flange extending its entire length, the table value should be reduced by about 40%.

TABLE 10

RATE OF AIR FLOW THROUGH SLOT-TYPE HOODS TO PRODUCE VELOCITY OF 100 FPM AT DIFFERENT DISTANCES FROM HOOD

$[Q = 2.8WLV]$

Tank or Table Length (ft)	*Q in Cubic Feet per Minute for These Distances from Hood*								
	6 in.	9 in.	12 in.	15 in.	18 in.	21 in.	24 in.	30 in.	36 in.
1	140	210	280	350	420	490			
1½	210	315	420	525	630	735	840		
2	280	420	560	700	840	980	1,120	1,400	
2½	350	525	700	875	1,050	1,225	1,400	1,750	2,100
3	420	630	840	1,050	1,260	1,470	1,680	2,100	2,520
3½	490	735	980	1,225	1,470	1,715	1,960	2,450	2,940
4	560	840	1,120	1,400	1,680	1,960	2,240	2,800	3,360
5	700	1,050	1,400	1,750	2,100	2,450	2,800	3,500	4,200
6	840	1,260	1,680	2,100	2,520	2,940	3,360	4,200	5,040
8	1,120	1,680	2,240	2,800	3,360	3,920	4,480	5,600	6,720
10	1,400	2,100	2,800	3,500	4,200	4,900	5,600	7,000	8,400
12	1,680	2,520	3,360	4,200	5,040	5,880	6,720	8,400	10,080
15	2,100	3,150	4,200	5,250	6,300	7,350	8,400	10,500	12,600
20	2.800	4,200	5,600	7,000	8,400	9,800	11,200	14,000	16,800

For tanks or table tops having slot hoods along two long sides or around the entire perimeter, L in equation 7 is the length in feet of the tank or table, not of the hoods, unless, of course, the value for W

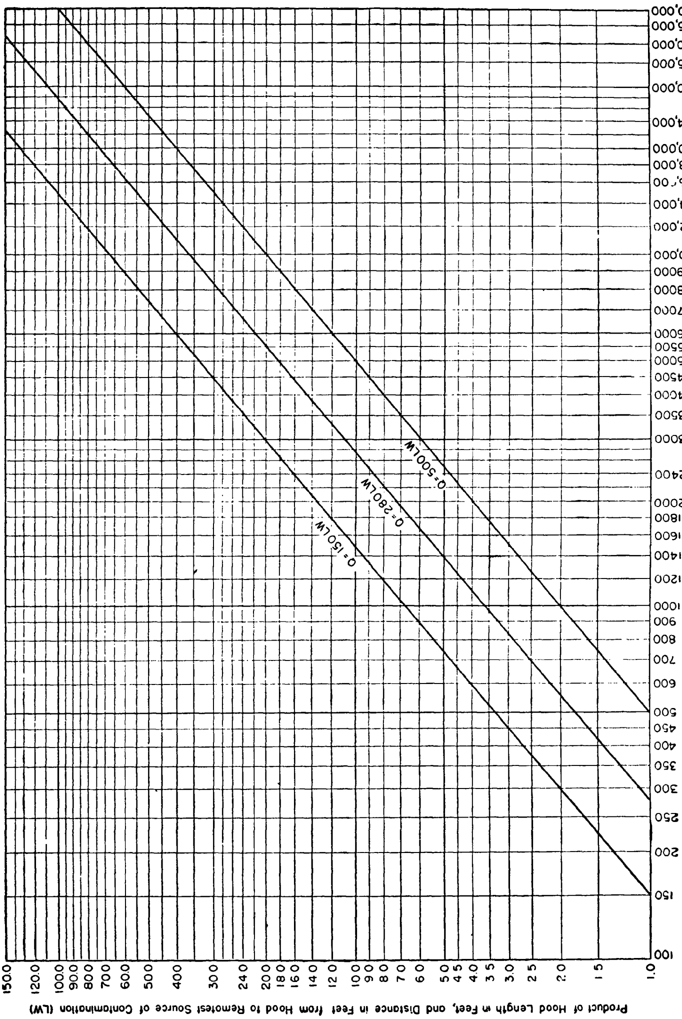


FIGURE 23. Air Volume for Slot-Type Hoods

is taken only as one-half of the distance between the slots. The easiest procedure is to let L represent the table or tank length (or the length of the part of the table where the contaminant is produced) and W the table or tank width, irrespective of whether a single slot

hood is used or hoods are located along more than one edge. If the table or tank width is over 20 in., slot hoods should be located along both long sides for best performance.

It should be noted that equation 7 and figure 23 give values of Q which will produce the desired control velocity at the distance W from the hood. Between the hood and the limit defined by the distance W, the control velocity is considerably higher than at the

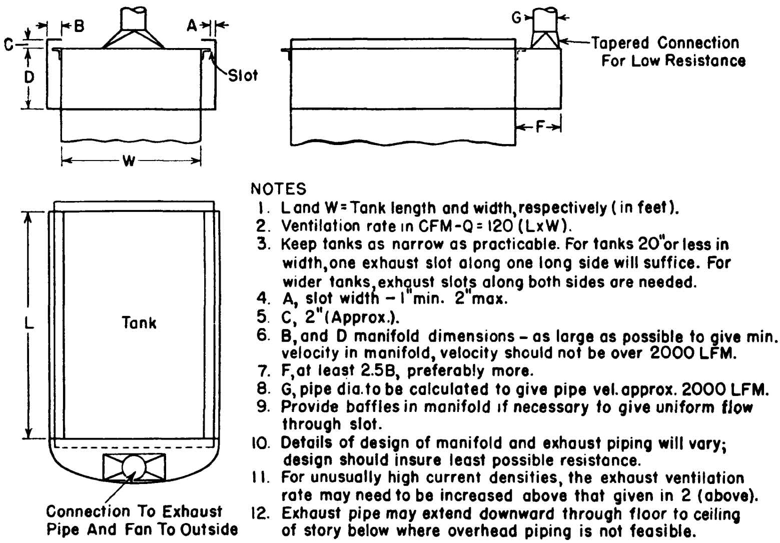


FIGURE 24. Ventilation of Electroplating Tank

distance W. Since it is not necessary in most instances to capture 100% of the contaminant it is often permissible to use much lower control velocities than those given in table 8. For example, it has been found by experience that a ventilation rate of $120WL$ is satisfactory for chrome plating.[68, 69, 70] In this instance, the control velocity at the far edge of the tank is only about 43 fpm, but it is, of course, more than 100 fpm over almost half of the tank. In addition, the dilution of the contaminated workroom air by the air exhausted through the hood is sufficient to keep the atmospheric concentration of chromic acid mist below the maximum allowable level. Likewise, for degreasing, the commonly used ventilation rate is $50WL$, which produces a minimum control velocity of about 18 fpm.[47, 71] This ventilation rate is often found to be inadequate if

there is any significant air disturbance near the tank. Higher ventilation rates, however, are avoided because of the excessive rate of solvent loss.[72] Since little or no local exhaust ventilation is needed for degreasing if the tank is of good design and if the operation is performed properly, and since a very high ventilation rate is needed if these conditions are grossly violated,[58, 71] there is no justification

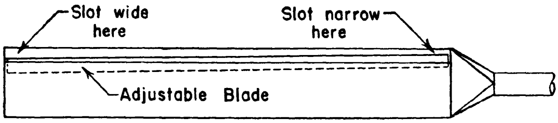


FIGURE 25. Adjustable Slot Hood

for increasing the recommended rate because of the economic factors involved.

Slot-type hoods as used at tanks are frequently quite long and present a problem in obtaining fairly uniform air flow over the entire length. This may be accomplished by any one of the following four procedures:

1. Have the duct or hood which forms the rear part of the slot of very large cross-sectional area so that there is very little pressure loss from the remote end of the slot to the end where it joins the duct (see figure 24).

2. Construct the slot portion of the hood so that the slot width may be adjusted. The rate of air flow into the slot (quantity, not velocity) may then be balanced by adjusting the slot so that it is of decreasing width as it approaches the end where it joins the duct (see figure 25).

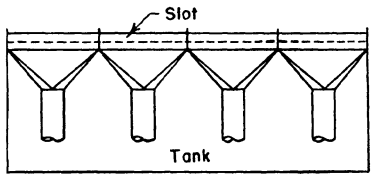


FIGURE 26. Multiple Exhaust Ducts at Slot-Type Hood

3. Construct long hoods in separate sections so that the flow from each will be the same and will be uniform over the relatively short lengths of the individual slot sections (see figure 26).

4. Construct the hood with vanes as shown in figure 27 to equalize the flow rate. The location of the vanes and the suggested hood dimensions may be determined from the data given in the figure.

Like rectangular and round hoods discussed previously, the velocity at some distance in front of the slot is a function of Q not of the slot

velocity. The influence of a very high slot velocity for a given value of Q is felt for only a few inches in front of the slot.[66] Yet it is not uncommon to find installations which were "improved" by decreasing the width of the slot and thereby obtaining higher slot velocities. Also, it is not unusual to find the ventilation rate for slot hoods given in terms of the slot velocity. This value, per se, means nothing as regards contaminant control unless the slot width is given also; in other words, the ventilation rate in cubic feet per minute.

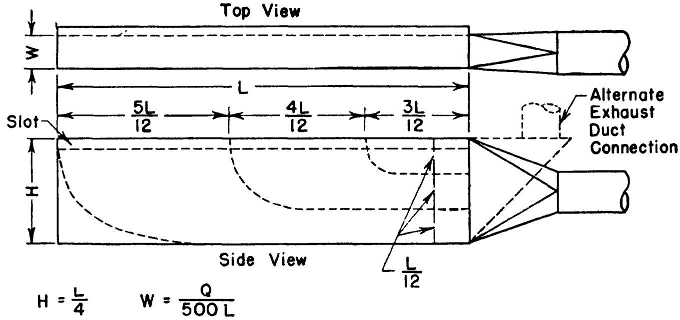


FIGURE 27. Guide Vanes in Slot-Type Hoods

Canopy Hoods. Hoods of this type are used above tanks, tables, furnaces, and the like (see figure 28). They are particularly satisfactory if the contaminated air is warmer than the room air and tends to rise. They should, however, not be used if the workers must lean over the source of contamination, because the contaminated air is merely drawn through the breathing zone of the workers. Canopy hoods were employed more widely in the past than they are today. A much-too-large percentage was employed on operations where the worker stood over the source of contamination; the trend today is to employ lateral or down-draft exhausts for jobs of this nature.

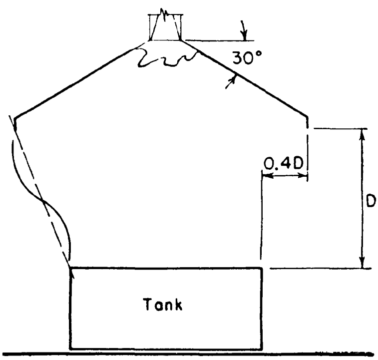


FIGURE 28. Suggested Canopy Hood Design

Canopy hoods are actually one class of rectangular or round hoods but their usual arrangement is such that the entering velocity pattern is markedly different from the conventional round or rectangular hood; hence, they are considered as a separate group. Very little work has been reported on the nature of air flow into different types of canopy hoods. However, figure 28 shows the approximate shape of a velocity contour at a typical hood.

In applying the fundamental equation, it is obvious that A is the entire area of opening between the hood and the upper edges of the surfaces beneath the hood—approximately PD (see figure 28). V is the average velocity through the opening, not the velocity at the upper edge of the table or tank. Thus

$$Q = PDV \tag{8}$$

where Q = quantity of air in cubic feet per minute.
P = perimeter of hood face in feet.
D = perpendicular distance in feet from hood face to top of tank or table.
V = average velocity through opening between hood edge and table or tank top.

Since the minimum control velocity should exist at the upper edge of the table or tank, the average velocity must be increased accordingly. Dalla Valle found that for canopy hoods of the approximate proportions shown in figure 28 and located about 3½ or 4 ft above the source of contamination, the velocity at the top edge of the tank or table was about 0.7 of the average velocity.[73] Hence the equation defining the minimum ventilation rate in terms of the minimum control velocity becomes

$$Q = 1.4PDV \tag{9}$$

where Q, P, and D are the same as in 8, and V is equal to the minimum control velocity in feet per minute.

It should be observed, however, that equation 9 applies only to canopy hoods as shown in figure 28 and as commonly found in industry. The constant will be as low as 1.0 if the canopy hood is only a negligible distance above the surface from which the contaminant escapes and will be greater than 1.4 if the distance between the hood and source of contamination is excessive.

From the practical viewpoint, canopy hoods are frequently unsatisfactory. It is not at all unusual to see carefully developed installations of this kind which are obviously falling far short of their

expected performance. At canopy hoods over hot tanks, for instance, one frequently sees the mist clouds rising rapidly toward the hood and then "spilling" out around it. This difficulty is usually caused by the influence of air currents within the room. The open area between the tank top and the hood is so great that very little inter-

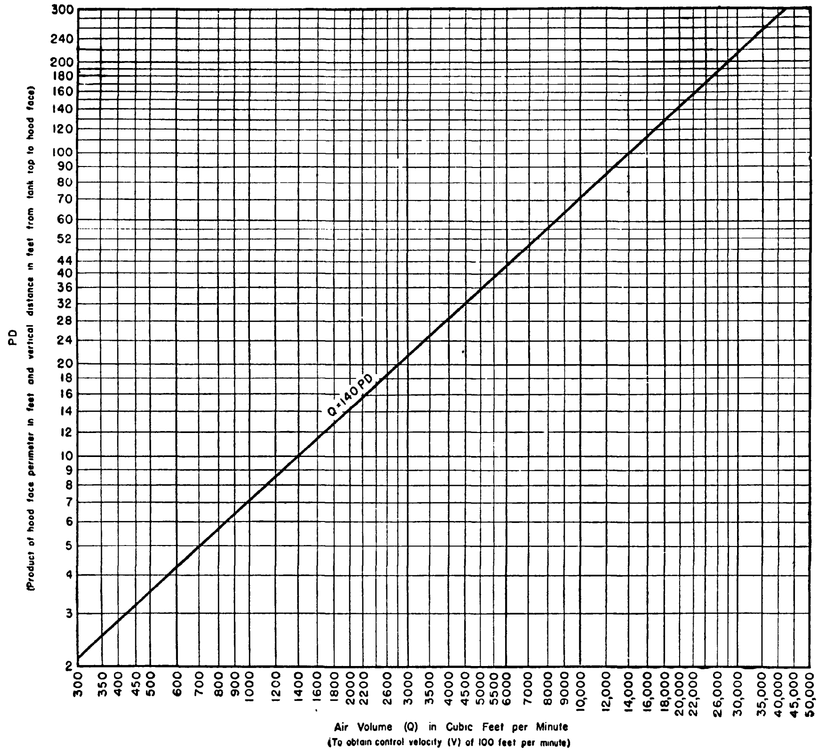


FIGURE 29. Air Volume Required for Canopy Hoods

ference is required to cause some of the contaminated air to escape. Also, convection currents caused by the heated tank frequently create a larger total volume of air flow toward the hood than it was designed to handle. The result is that many canopy hoods are not doing a good job of control.

Equation 9 is plotted in figure 29 so that the required ventilation rate may be read direct if the area of the opening (*PD*) is known and the minimum control velocity is 100 fpm. For different control velocities the value of *Q* must be changed proportionately, but for

most operations where canopy hoods are used a control velocity of 100 fpm is adequate, if external air movement can be controlled.

Streamlining Hoods. Abrupt changes in velocity or in direction of air flow are attendant with considerable energy losses. Careful hood shaping will reduce these losses to a minimum and will result in substantial power saving, sufficient in many systems to justify the additional cost involved in streamlining the hoods, transformation ducts, bends, and the like.

For example, the energy loss at a plain suction end of a round, square, or rectangular duct is about 100% of the velocity pressure in the duct. By adding a flange at the end of the duct and perpendicular to the sides of it, the loss is about 50% of the velocity head in the duct. In addition, the velocity contour pattern at the duct is so altered that the quantity of air needed to produce the same control velocity at a prescribed distance from the hood may be decreased 20%. If a tapered or bell-shaped transformation piece is installed between the flange and the duct so that the flange is eliminated and the face or large end of the transformation piece is the same size as the outer edge of the flange, the energy loss at entrance will be less than 25% of the velocity pressure in the duct. A flange at the face or large end of this transformation piece will further decrease the energy loss a little. If the transformation piece is bell shaped forming a contracting nozzle with a radius of curvature not less than one duct diameter, the entrance energy loss is less than 3% of the velocity head in the connecting duct.

It is obvious, therefore, that the pressure loss or resistance offered by a hood or duct terminal varies from almost zero to about one velocity head. Since the fan horsepower varies as the resistance against which it must operate, and since the velocity head is frequently in the order of 10% to 30% of the total resistance of the system, it becomes apparent that a real saving in horsepower can be accomplished by streamlining hoods. For more specific data on hood entrance losses the reader is referred to the following chapter.

CHAPTER VI

DESIGN OF LOCAL EXHAUST SYSTEMS

This chapter is a continuation of the preceding one and will deal largely with the considerations and calculations involved in determining pipe, collector, and exhauster sizes, and in selecting the pipe or duct. Most of the calculations involved can be made with considerable precision and corrected for almost all abnormal conditions, such as temperature, humidity, altitude, and viscosity. Such apparent precision is usually needless, however, since refinements of this nature are overbalanced many times by other influences which cannot be taken into proper consideration, such as changes in operations, open doors or windows, and air movement from other machines. The other extreme must be guarded against also. This consists of the design of systems by rule-of-thumb methods, or, even worse, turning it over to some sheet-metal contractor or "tin knocker," who rarely makes any but the most mediocre design calculations. The "happy medium" must be the goal of engineers. All factors and conditions which influence the final operation of the system must be given the consideration which they require—no more, no less. The tables, charts, and design procedures contained in this chapter will, it is believed, give the engineer all the data he needs to design systems which will function properly without his having to resort to needlessly long and complicated calculations.

Design Procedures. Though there are a number of different calculation procedures which may be followed to obtain satisfactory results the two which are probably most common are (1) sizing the ducts on the basis of transport velocity and system balance, and (2) sizing the ducts on the basis of transport velocity only and obtaining balance by means of blast gates. Both procedures have certain features to recommend them as will be seen from the following discussions. The second procedure is the simpler of the two.

BALANCED SYSTEM DESIGN

To obtain a balanced system through design it is necessary that the ductwork upstream from the exhauster be of such size that the total pressure (*TP*)* (negative) at every junction be the same for both ducts extending upstream from the junction. Obviously, it is impossible to have a *TP* of 2 in. of water at the point in a main duct where a branch duct enters and to have only 1-in. *TP* in the downstream end of the branch duct. For this reason it is unwise to exhaust operations producing widely dissimilar materials by a single system. It is better to use separate systems for the different types of contaminant to be handled.

The design of the ductwork entails the calculation of the *TP* in both ducts at all points of junction and to alter the duct sizes upstream thereof as necessary to accomplish a balance. An inspection of the ductwork layout will reveal which branch duct is located most unfavorably (usually the one most remote from the exhauster). The design calculations should be started with the branch having the greatest resistance, and the other parts of the system should be proportioned accordingly. The *TP* must be determined for each duct section lying upstream from each junction or point where *Q* changes. The various steps involved in the design of a complete duct system for a typical layout will be demonstrated later in sample calculations.

The *TP* of a single-branch duct is made up of the velocity pressure (*VP*) and the resistance pressure (*RP*). The *RP* is a measure of the energy loss involved in moving the air through the hood, duct, and accessories and is comparable to the frictional resistance involved in moving any object or material. It is made up of the resistance at the hood, the resistance in the straight duct, the resistance in the bends, the resistance in enlargements or contractions, the resistance in any other restrictions, such as chip traps or dust collectors, and the resistance at the entrance to the main duct.

The steps involved in the calculation of the *TP* of a branch duct are:

1. Calculate or select the transport velocity.
2. Determine the *VP*.
3. Determine the hood-entrance loss in terms of the *VP*.

* See Figures II and III in the Appendix for illustrations and for discussion of pressures and air flow in supply and exhaust ducts.

4. Determine the straight-duct equivalent of the bends.
5. Determine the total equivalent length of straight ducts and the resistance in terms of *VP*.
6. Determine other energy losses, such as contractions, enlargements, chip traps, and collectors (if any), in terms of the *VP*.
7. Determine the main-duct entrance loss in terms of the *VP*.
8. Add the values obtained in 2, 3, 5, 6, and 7 to obtain the *TP* in terms of the *VP*.

The calculations for any section of the main duct are similar, except that the *TP* existing at the upstream point is substituted for 2, 3, and 7 in determining the *TP* at the downstream end of the section.

1. *Transport Velocity.* In local exhaust systems, the determining factor as regards the minimum duct velocity is the nature of the contaminant to be transported. Duct velocities vary from as little as 1500 to 2000 fpm for gases or vapors to as much as 5500 for heavy dusts like lead. As a rule, the velocity is kept as low as is consistent with good conveyance of the contaminant to conserve power consumption, but infrequently it is preferable to employ higher duct velocities and smaller duct sizes to accomplish a better structural design (that is, fewer elbows and offsets) or to interfere less with workers and equipment.

The minimum velocity necessary for transport of the contaminant may be computed by means of the following equation,[74] but it is more convenient to use table 11 which lists duct velocities commonly used for different contaminants:

$$V = 6000\left(\frac{S}{S+1}\right)p^{0.4} \tag{10}$$

where V = duct velocity in feet per minute.
S = specific gravity of the contaminant.
p = particle diameter in inches.

That it is not good practice to exhaust unlike materials in the same system is apparent from the duct velocities recommended in table 11 for transporting different types of contaminants. To balance the system, the resistance in the section handling vapors, for example, must be of the same order of magnitude as the resistance in the branch handling the material hard to transport, such as coarse lead dust, and, since the power consumption varies approximately as the

TABLE 11

RECOMMENDED MINIMUM TRANSPORT VELOCITIES

Nature of Contaminant	*Examples*	*Duct Velocity*
Vapors, gases, smokes, fumes, and very light dusts	All vapors, gases, and smokes; zinc and aluminum oxide fumes; wood flour and cotton lint	2000 fpm
Medium-density dry dusts	Cotton, buffing and jute lint; wood, grain, rubber, and Bakelite dust	3000 fpm
Average industrial dust	Wool; wood, sand blast, grinding, and shoe dust; wood shavings	4000 fpm
Heavy dusts	Lead and foundry shakeout dusts; metal turnings; jute butts	5000 fpm
Large particles of heavy, moist materials	Moist lead or foundry dust	5000 fpm and over

cube of the duct velocity, such arrangement is very wasteful of power even though economical to install.

2. *The Velocity Pressure.* Since ductwork is usually constructed only to standard sizes, such as the half inch for small circular ducts and the even inch for larger ones, it is necessary to calculate the true duct velocity using the minimum transport velocity as a guide. For branch ducts, the nearest smaller standard size is commonly selected so that the transporting velocity will not fall below the desired value. The pipe area may be computed by means of the following equation:

$$A = \frac{Q}{V} \tag{11}$$

where A = the duct area in square feet.
Q = the quantity of air in cubic feet per minute.
V = minimum transport velocity in feet per minute.

From A, the duct diameter (or dimensions, if rectangular) can be determined. For round pipe, however, the diameter is given directly by

$$d = 13.5\left(\frac{Q}{V}\right)^{0.5} \tag{12}$$

where d = the duct diameter in inches and Q and V are the same as in 11.

Unless the value of d happens to be only slightly below a standard size, the next smaller size pipe is selected, and the actual duct velocity is determined by solving for V in equation 11 or for round ducts by

$$V = \frac{183Q}{d^2} \tag{13}$$

where V = the average duct velocity in feet per minute.
Q = the quantity of air in cubic feet per minute.
d = the diameter of the duct in inches.

The velocity pressure may then be calculated by

$$VP = \left(\frac{V}{4005}\right)^2 \tag{14}$$

where VP = the velocity pressure in inches of water.
V = the average duct velocity in feet per minute.

For the sake of convenience, the velocity pressures for different velocities have been tabulated in table 12, and the areas of round pipes in square feet for different standard diameters in inches are given in table 13. Also, since figure 6 is a plot of the interrelationship of Q, V, and A, it can be used to read direct the data given by equation 11. However, all of these data have been plotted on one graph in a very convenient form to speed the calculations (see figure 30).

For example, determine the duct size, the true velocity, and the VP for a duct to handle 1000 cfm and to have a minimum transport velocity of 3000 fpm. *Solution:* select the 1000-cfm line at the top of figure 30, and follow it diagonally downward to the 3000-fpm duct velocity line (see left of figure for duct velocity). The exact pipe diameter is read as about 7.8 in. Select the next smaller standard duct, 7.5 in., and follow it vertically to the 1000 cfm line, and read the true velocity—about 3250 fpm. Follow the dot-and-dash line to the right and read the VP—0.66-in. water gage. Thus very rapidly and in one more or less continuous movement these calculations are accomplished.

Data very similar to those given in figure 30 are included in table 14 for those who prefer tables. Using the 3000-fpm column in the table it is apparent that the duct size which will convey 1000 cfm at a velocity not less than 3000 fpm is 7.5 in. Knowing this, the actual velocity and VP may be computed from equations 13 and 14 or obtained from tables 12 and 13.

3. *Hood Loss.* The energy loss or resistance at the hood varies widely, depending upon its shape. This loss usually is due largely

to the contraction of the air stream as it enters the throat of the hood. The greater this contraction (that is, the lower the percentage

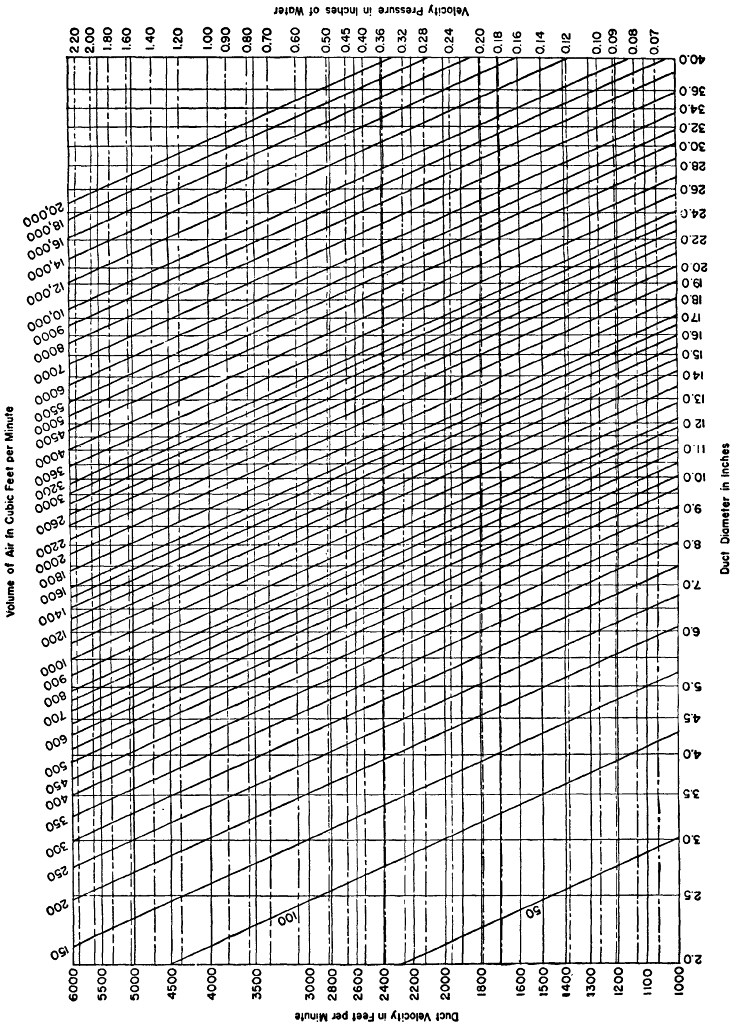


FIGURE 30. Duct Diameter, Air Volume, Duct Velocity, Velocity Head Relationship

of the hood throat area actually occupied by the air stream), the lower is the coefficient of entrance (C_e), and the greater is the energy loss at entrance. A significant part of the hood entrance loss is

TABLE 12

VELOCITY PRESSURES FOR DIFFERENT VELOCITIES

$$\left[VP = \left(\frac{V}{4005}\right)^2\right]$$

[Velocity (V) in feet per minute and velocity pressure (VP) in inches of water]

VP	V	VP	V	VP	V	VP	V	VP	V	VP	V
0.06	981	0.43	2626	0.80	3582	1.17	4332	1.54	4970	1.91	5535
0.07	1060	0.44	2656	0.81	3604	1.18	4350	1.55	4986	1.92	5550
0.08	1133	0.45	2687	0.82	3625	1.19	4368	1.56	5002	1.93	5564
0.09	1201	0.46	2716	0.83	3657	1.20	4386	1.57	5018	1.94	5579
0.10	1266	0.47	2746	0.84	3669	1.21	4405	1.58	5034	1.95	5593
0.11	1328	0.48	2775	0.85	3690	1.22	4423	1.59	5050	1.96	5608
0.12	1387	0.49	2804	0.86	3709	1.23	4442	1.60	5066	1.97	5623
0.13	1444	0.50	2832	0.87	3729	1.24	4460	1.61	5082	1.98	5637
0.14	1498	0.51	2860	0.88	3758	1.25	4478	1.62	5098	1.99	5651
0.15	1551	0.52	2888	0.89	3779	1.26	4495	1.63	5114	2.00	5664
0.16	1602	0.53	2916	0.90	3800	1.27	4513	1.64	5129	2.01	5678
0.17	1651	0.54	2943	0.91	3821	1.28	4531	1.65	5144	2.02	5692
0.18	1699	0.55	2970	0.92	3842	1.29	4549	1.66	5160	2.03	5706
0.19	1746	0.56	2997	0.93	3863	1.30	4566	1.67	5175	2.04	5720
0.20	1791	0.57	3024	0.94	3884	1.31	4583	1.68	5191	2.05	5734
0.21	1835	0.58	3050	0.95	3904	1.32	4601	1.69	5206	2.06	5748
0.22	1879	0.59	3076	0.96	3924	1.33	4619	1.70	5222	2.07	5762
0.23	1921	0.60	3102	0.97	3945	1.34	4636	1.71	5237	2.08	5776
0.24	1962	0.61	3127	0.98	3965	1.35	4653	1.72	5253	2.09	5790
0.25	2003	0.62	3153	0.99	3985	1.36	4671	1.73	5268	2.10	5804
0.26	2042	0.63	3179	1.00	4005	1.37	4688	1.74	5283	2.11	5817
0.27	2081	0.64	3204	1.01	4025	1.38	4705	1.75	5298	2.12	5831
0.28	2119	0.65	3229	1.02	4045	1.39	4722	1.76	5313	2.13	5845
0.29	2157	0.66	3254	1.03	4064	1.40	4739	1.77	5328	2.14	5859
0.30	2193	0.67	3279	1.04	4084	1.41	4756	1.78	5343	2.15	5872
0.31	2230	0.68	3303	1.05	4103	1.42	4773	1.79	5359	2.16	5886
0.32	2260	0.69	3327	1.06	4123	1.43	4790	1.80	5374	2.17	5899
0.33	2301	0.70	3351	1.07	4142	1.44	4806	1.81	5388	2.18	5913
0.34	2335	0.71	3375	1.08	4162	1.45	4823	1.82	5403	2.19	5927
0.35	2369	0.72	3398	1.09	4181	1.46	4840	1.83	5418	2.20	5940
0.36	2403	0.73	3422	1.10	4200	1.47	4856	1.84	5433	2.21	5954
0.37	2436	0.74	3445	1.11	4219	1.48	4873	1.85	5447	2.22	5967
0.38	2469	0.75	3468	1.12	4238	1.49	4889	1.86	5462	2.23	5981
0.39	2501	0.76	3491	1.13	4257	1.50	4905	1.87	5477	2.24	5994
0.40	2533	0.77	3514	1.14	4276	1.51	4921	1.88	5491	2.25	6008
0.41	2563	0.78	3537	1.15	4295	1.52	4938	1.89	5506		
0.42	2595	0.79	3560	1.16	4314	1.53	4954	1.90	5521		

produced at the entrance to the hood if the face velocity is high. The coefficient of entry will vary from as low as about 0.6 for a sharp-edged orifice to as high as 1.0 for a streamlined, bell-shaped entrance. Figures 31 to 43 inclusive show different typical hood shapes with

TABLE 13

DUCT AREAS

(Round ducts)

Duct Diameter in Inches	Duct Area in Square Feet	Duct Diameter in Inches	Duct Area in Square Feet	Duct Diameter in Inches	Duct Area in Square Feet	Duct Diameter in Inches	Duct Area in Square Feet
2	0.0218	10	0.5454	18	1.767	32	5.585
2½	0.0341	10½	0.6010	18½	1.867	33	5.940
3	0.0491	11	0.6600	19	1.969	34	6.305
3½	0.0668	11½	0.7215	19½	2.074	35	6.681
4	0.0873	12	0.7854	20	2.182	36	7.069
4½	0.1104	12½	0.8520	21	2.405	37	7.467
5	0.1364	13	0.9218	22	2.640	38	7.876
5½	0.1650	13½	0.9937	23	2.885	39	8.296
6	0.1964	14	1.069	24	3.142	40	8.727
6½	0.2304	14½	1.146	25	3.409	42	9.621
7	0.2673	15	1.227	26	3.687	44	10.56
7½	0.3068	15½	1.310	27	3.976	46	11.54
8	0.3491	16	1.396	28	4.276	48	12.57
8½	0.3942	16½	1.485	29	4.587	50	13.64
9	0.4418	17	1.576	30	4.909	55	16.50
9½	0.4923	17½	1.670	31	5.241	60	19.63

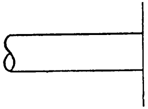
the corresponding coefficients of entry and the energy loss in terms of the *VP* at the throat of the hood. The C_e for tapered hoods will vary with the proportions of the hood. Table 15 contains the different coefficients of entry for tapered hoods of different proportions. Additional data on this subject are given in Chapter IX. The method of determining the included angle (θ) or the ratio $L/(D - d)$ is illustrated in figure 44.

If the coefficient of the hood entry is known (use figures 31 to 43 as a guide), the hood entrance loss (h_e) in percentage of the *VP* at

Plain Duct End

Ce = 0.72
he = 0.93VP

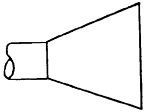
FIGURE 31



Flanged Duct End

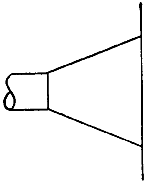
Ce = 0.82
he = 0.49VP

FIGURE 32



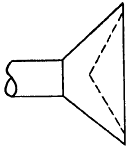
Tapered Cone, or
Rectangular to Round
Ce = 0.82 to 0.98
(See Table 15)

FIGURE 33



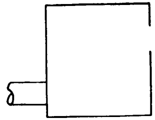
Flanged Tapered Cone, or
Rectangular to Round
Ce = 0.82 to 0.98
(See Table 15)

FIGURE 34



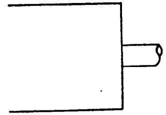
Double Tapered Hood
with Inner Cone
Ce = 0.70 (approx.)
he = 1.04 VP

FIGURE 35



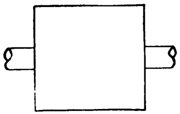
Sharp Edge Orifice plus
Flanged Duct End
Ce = 0.55
he = 2.3 VP

FIGURE 36



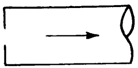
Exhaust Booth –
Fundamentally same as
Figure 32
Ce = 0.82
he = 0.49 VP

FIGURE 37



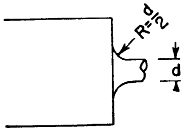
Abrupt Enlargement,
Settling Chamber,
or Trap
Ce = 0.63 (approx.)
he = 1.5 VP

FIGURE 38



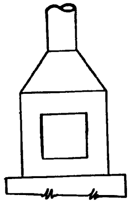
Sharp Edge Orifice
Ce = 0.60
he = 1.78 VP

FIGURE 39



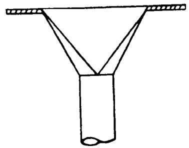
Bell-Shaped Duct
Connection
(compare with Fig. 37)
Ce = 0.97
he = 0.06VP

FIGURE 40



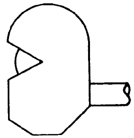
Hood, as over Lead
Pot, Low Face Velocity
Fundamentally same as
Figure 33
Ce = 0.82 to 0.98
(See Table 15)

FIGURE 41



Bench or Table
Downdraft Exhaust
Fundamentally same as
Figure 34
Ce = 0.82 to 0.98
(See Table 15)

FIGURE 42



Grinding-Wheel Hood
Somewhat similar to
Figure 37
Ce = 0.80
he = 0.56 VP

FIGURE 43

Energy Loss and Coefficient of Entry at Some Suction Openings

the throat of the hood may be determined by means of the following equation:

$$h_e = 100\left(\frac{1 - C_e^2}{C_e^2}\right) \tag{15}$$

where h_e = hood entrance loss in percentage of *VP*.

C_e = coefficient of hood entry.

The hood entrance losses in percentages of the *VP*'s for different entry coefficients are listed in table 16 from which they may be read conveniently.

The types and shapes of hoods encountered in industry today are many and varied. Some are quite complicated so that it is merely guesswork to attempt to choose an over-all coefficient of entry. However, most complex

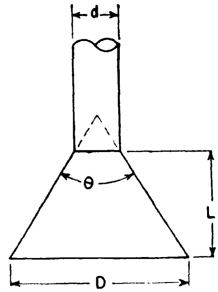


FIGURE 44. Included Angle for Hoods, and Duct Enlargements or Contractions (See Tables 15 and 22)

TABLE 14

QUANTITY OF AIR HANDLED BY DUCTS

(Air quantity in cubic feet per minute)

Diameter of Duct in Inches	*Duct Velocity in Feet per Minute*								
	2000	2500	3000	3500	4000	4500	5000	5500	6000
3	98	123	147	172	197	221	246	270	295
3½	134	167	200	234	267	300	334	367	400
4	175	218	262	306	350	393	437	480	524
4½	221	276	331	387	442	497	552	608	663
5	273	341	409	478	546	614	682	750	818
5½	330	413	495	578	660	742	825	908	990
6	393	491	589	688	786	884	982	1080	1180
6½	461	576	692	807	923	1040	1155	1270	1385
7	534	668	802	936	1070	1205	1340	1470	1605
7½	614	768	922	1075	1230	1380	1535	1690	1845
8	699	874	1050	1220	1395	1570	1745	1920	2095
8½	789	987	1185	1380	1575	1775	1970	2165	2365
9	882	1105	1325	1545	1765	1990	2210	2430	2650
9½	985	1230	1475	1720	1965	2210	2460	2705	2950
10	1090	1365	1635	1910	2180	2455	2730	3000	3275
10½	1200	1500	1805	2105	2405	2705	3005	3305	3605
11	1320	1650	1980	2310	2640	2970	3300	3630	3960
11½	1440	1800	2160	2520	2880	3240	3605	3965	4325
12	1570	1960	2355	2745	3140	3530	3925	4320	4710
13	1840	2300	2760	3220	3680	4140	4600	5065	5525
14	2140	2675	3210	3745	4280	4815	5350	5885	6420
15	2455	3065	3680	4295	4910	5525	6140	6750	7365

hoods can be broken down into a series of individual hoods, the coefficients of entry of which can be estimated individually by reference to figures 31 to 43 inclusive. The over-all C_e can be computed by determining from figures 31 to 43 and tables 15 and 16 the individual *VP*'s, adding them, and then from table 16 obtaining the composite C_e. For example, the hood shown in figure 36 is similar to a succession of the two hoods shown in figures 32 and 39. The entrance losses of these hoods are $0.49VP$ and $1.78VP$ which total $2.27VP$. From table 16 the composite C_e is found to be 0.55.

4. *Bends, Straight Duct Equivalent.* The energy loss or resistance pressure for bends is not the same as for a similar length of straight

TABLE 15

COEFFICIENTS OF ENTRY FOR TAPERED OR BELL-SHAPED HOODS OF DIFFERENT PROPORTIONS

(D more than $1.4d$ in figure 44; flanged or unflanged)

Included Angle (θ) in Degrees (Figure 44)	Ratio $\frac{L}{D-d}$ (Figure 44)	Round		Square or Rectangular	
		Throat Diameter 8 In. and Larger	Throat Diameter Less Than 8 In.	Throat Diameter 8 In. and Larger	Throat Diameter Less Than 8 In.
0° or 360° *	—	0.72	0.70	0.70	0.68
10	5.7	0.93	0.89	0.88	0.84
20	2.8	0.96	0.91	0.94	0.89
30	1.9	0.98	0.92	0.95	0.89
40	1.4	0.99	0.93	0.95	0.90
50	1.07	0.98	0.92	0.95	0.89
60	0.87	0.98	0.92	0.94	0.88
75	0.65	0.96	0.91	0.93	0.87
90	0.50	0.95	0.90	0.91	0.85
120	0.29	0.91	0.86	0.87	0.82
150	0.13	0.86	0.82	0.83	0.79
180 †	—	0.81	0.79	0.80	0.77
225	—	0.78	0.76	0.77	0.75
270	—	0.75	0.74	0.74	0.72
315	—	0.73	0.72	0.72	0.70
360° or 0° *	—	0.72	0.70	0.70	0.68

* Unflanged duct ends.

† Flanged duct ends.

TABLE 16

PRESSURE LOSS AT HOOD ENTRANCE IN PERCENTAGE OF VELOCITY PRESSURE AT THROAT FOR DIFFERENT COEFFICIENTS OF ENTRY

$$\left[h_e = 100\left(\frac{1 - C_e^2}{C_e^2}\right)\right]$$

Coefficient of Entry	Hood Entrance Loss in Percentage of Velocity Pressure at Throat	Coefficient of Entry	Hood Entrance Loss in Percentage of Velocity Pressure at Throat	Coefficient of Entry	Hood Entrance Loss in Percentage of Velocity Pressure at Throat
1	0	0.83	45	0.66	130
0.99	2.0	0.82	49	0.65	137
0.98	4.2	0.81	52	0.64	144
0.97	6.4	0.80	56	0.63	152
0.96	8.7	0.79	60	0.62	160
0.95	11	0.78	65	0.61	169
0.94	13	0.77	69	0.60	178
0.93	16	0.76	73	0.59	187
0.92	18	0.75	78	0.58	197
0.91	21	0.74	83	0.57	208
0.90	23	0.73	88	0.56	219
0.89	26	0.72	93	0.55	230
0.88	29	0.71	98	0.54	242
0.87	32	0.70	104	0.53	256
0.86	35	0.69	110	0.52	270
0.85	38	0.68	116	0.51	285
0.84	42	0.67	123	0.50	300

duct but can be expressed conveniently in terms of the length in feet of straight duct which has the same *RP*. The *RP* for bends varies with the degree of curvature and with the amount of bend. The equivalent length of straight duct for different bends may be calculated by means of the following equation:

$$EDL = K\theta d^{1.2} \tag{16}$$

where EDL = equivalent length of straight duct in feet.
K = a constant which varies with the degree of curvature (radius of bend) as shown in table 17.
θ = the angle of bend in degrees.
d = the duct diameter in inches.

It is good practice to construct all bends with a centerline radius of at least 2½ pipe diameters. The equivalent straight duct in feet for different bends having a radius of bend of 2½d and for different sizes of duct are tabulated in table 18 to simplify the design calculations. For other degrees of curvature the values selected from table 18 must be multiplied by an appropriate factor, as shown in table 19. The equivalent straight duct length of bends greater than 90° may be computed by equation 16 or by increasing the 90° value from table 18 proportionally.

TABLE 17

VALUES OF K IN EQUATION 16 FOR BENDS OF DIFFERENT RADII

Centerline Radius of Bend in Terms of Duct Diameter	*Value of K in Equation 16*
1	0.0273
1¼	0.0195
1½	0.0140
1¾	0.0109
2	0.0094
2¼	0.0086
2½	0.0078
2¾	0.0086
3	0.0094

5. *Resistance Pressure of Straight Ducts.* To calculate the RP of the ductwork including the bends, the total length in feet of straight duct in the branch to the point of junction with another duct is determined, and to this is added the equivalent length in feet of straight ducts as found in 4 above for the bends. (The length, if significant, of the converging or diverging sections as given under 6 should be included in the straight duct length.) The RP can be computed by using the following equation:

$$RP = \frac{0.058LQ^{1.91}}{Cd^5} \tag{17}$$

where RP = the duct resistance pressure in inches of water.
L = the total length in feet of ducts including the straight duct equivalent of the bends.
Q = quantity of air in cubic feet per minute.
C = coefficient of roughness from table 20.
d = duct diameter in inches.

TABLE 18

RESISTANCE TO AIR FLOW IN ELBOWS AND BENDS
CENTERLINE RADIUS OF BEND = 2.5d

$[EDL = 0.0078\theta d^{1.2}]$

Duct Diameter in Inches	Equivalent Duct Length in Feet for Different Degree Bends					Duct Diameter in Inches	Equivalent Duct Length in Feet for Different Degree Bends				
	15°	30°	45°	60°	90°		15°	30°	45°	60°	90°
3	0.4	0.9	1.3	1.7	2.6	13	2.6	5.1	7.7	10.4	15.4
3.5	0.5	1.0	1.6	2.1	3.1	14	2.9	5.6	8.4	11.3	16.9
4	0.6	1.2	1.8	2.4	3.6	15	3.2	6.1	9.2	12.3	18.4
4.5	0.7	1.4	2.1	2.8	4.2	16	3.4	6.6	9.9	13.3	19.9
5	0.8	1.6	2.4	3.2	4.8	17	3.7	7.2	10.7	14.3	21.5
5.5	0.9	1.8	2.7	3.6	5.4	18	3.9	7.7	11.4	15.3	23.0
6	1.0	2.0	3.0	4.0	6.0	19	4.2	8.2	12.2	16.3	24.5
6.5	1.1	2.2	3.3	4.4	6.6	20	4.4	8.7	13.0	17.3	26
7	1.2	2.4	3.6	4.8	7.2	21	4.7	9.2	13.8	18.4	28
7.5	1.3	2.6	3.9	5.2	7.8	22	4.9	9.7	14.5	19.4	29
8	1.4	2.8	4.2	5.6	8.5	23	5.2	10.2	15.3	20.4	31
8.5	1.5	3.0	4.5	6.1	9.2	24	5.4	10.7	16.1	21.4	32
9	1.7	3.2	4.9	6.6	9.8	25	5.7	11.3	16.9	22.5	34
9.5	1.8	3.5	5.2	7.1	10.5	26	5.9	11.8	17.7	23.6	35
10	1.9	3.7	5.6	7.5	11.2	27	6.2	12.3	18.5	24.7	37
10.5	2.0	3.9	5.9	8.0	11.9	28	6.5	12.9	19.3	26	39
11	2.2	4.2	6.3	8.5	12.6	29	6.8	13.4	20.1	27	40
11.5	2.3	4.4	6.6	9.0	13.3	30	7.1	13.9	20.8	28	41
12	2.4	4.7	7.0	9.4	14.0	36	8.6	17.2	26	34	52

The foregoing equation gives the *RP* in inches of water, but as will be shown later the design calculations involved in balancing a system are simplified considerably if all energy losses in branch ducts are expressed in terms of the *VP*. To accomplish this, equation 17 can be converted to the following form:

$$L = 0.0365CdQ^{0.09} \tag{18}$$

where L = length in feet of duct which will have an energy loss (*RP*) of one *VP*.
C = coefficient of roughness from table 20.
d = duct diameter in inches.
Q = quantity of air in cubic feet per minute.

TABLE 19

FACTORS BY WHICH VALUES FROM TABLE 18 MUST BE MULTIPLIED FOR BENDS HAVING RADII OTHER THAN 2.5*d*

Centerline Radius of Bend in Terms of Duct Diameter	*Factor by Which Value from Table 18 Must Be Multiplied*
1	3.5
1¼	2.5
1½	1.8
1¾	1.4
2	1.2
2¼	1.1
2½	1.0
2¾	1.1
3	1.2

TABLE 20

COEFFICIENT OF ROUGHNESS FOR DIFFERENT TYPES OF DUCTWORK

(To be used in equations 17 and 18)

Type of Ductwork	*Coefficient of Roughness*
Excellent, smooth pipes	60
Average exhaust system of good design	55
Not-too-well-designed system with rough ducts	40
Old, bent, and damaged ducts (also most flexible metal hose)	30

The values obtained from the foregoing equation are given in table 21 for different duct sizes and types of ductwork, from which the length of duct in feet which has an *RP* of one *VP* may be read directly. (It should be noted that the values in the table are for a transporting velocity of about 4000 and introduce only a negligible error for velocities from 2000 to 5500 fpm.) The *RP* of the total length of duct in a branch, or section of main duct, in terms of *VP* is then determined by dividing *L* from table 21 into the total duct length in feet.

Round ducts are preferred and should be used in local exhaust systems wherever practicable. Nevertheless, it is sometimes necessary to use rectangular ducts. This introduces an additional step in calculating the *RP* of the ductwork. The recommended procedure is to determine the diameter of the equivalent round duct and then to employ the tables, figures, and equations for round ducts. This may be done by using the following equation:

$$d = 1.075\sqrt{xy} \tag{19}$$

where d = diameter of equivalent round duct in inches.
x and y = the dimensions in inches of the rectangular duct.

Equation 19 is plotted in figure 45 enabling the designer to read the equivalent round duct diameter directly for most of the duct sizes encountered in industrial local exhaust systems. For example, referring to figure 45, a rectangular duct 12 in. by 18 in. (216 sq in.) is found to be equivalent to a 16-in. diameter duct.

6. *Other Energy Losses.* Equipment such as chip traps, settling chambers, and dust collectors is frequently found in local exhaust systems. Such equipment introduces additional pressure losses which must be determined and included in the total *RP* of the section in which it is located. Duct enlargements or contractions are frequently necessary to make connection to equipment such as fans or

TABLE 21

LENGTH OF STRAIGHT DUCT WHICH HAS AN *RP* OF 1*VP*

$[L = 0.0365CdQ^{0.09}]$

Duct Length in Feet for Resistance of 1*VP*					Duct Length in Feet for Resistance of 1*VP*				
Duct Diameter in Inches	Very Smooth Ducts	Average Duct Construction	Rough Ducts	Old, Bent, Damaged Ducts	Duct Diameter in Inches	Very Smooth Ducts	Average Duct Construction	Rough Ducts	Old, Bent, Damaged Ducts
3	11	9.7	7.1	5.3	13	60	55	40	30
3.5	13	12	8.4	6.3	14	65	60	43	32
4	15	14	9.9	7.4	15	70	65	47	35
4.5	17	16	11	8.5	16	76	70	51	38
5	19	18	13	9.7	17	82	75	55	41
5.5	22	20	14	11	18	88	81	59	44
6	24	22	16	12	19	94	86	63	47
6.5	26	24	18	13	20	100	92	67	50
7	29	26	19	14	21	106	97	71	53
7.5	31	29	21	16	22	112	102	74	56
8	34	31	22	17	23	117	107	78	59
8.5	36	33	24	18	24	123	113	82	62
9	39	35	26	19	25	129	118	86	65
9.5	41	38	27	21	26	135	124	90	68
10	44	40	29	22	27	141	129	94	71
10.5	46	42	31	23	28	147	135	98	74
11	49	45	33	24	29	153	141	102	77
11.5	52	47	34	26	30	160	146	106	80
12	55	50	36	27	36	200	184	133	100

collectors which have standard size apertures at the inlet and outlet. They are found, only too frequently, in main ducts at ill-chosen places to increase the duct area to accommodate increases in Q and,

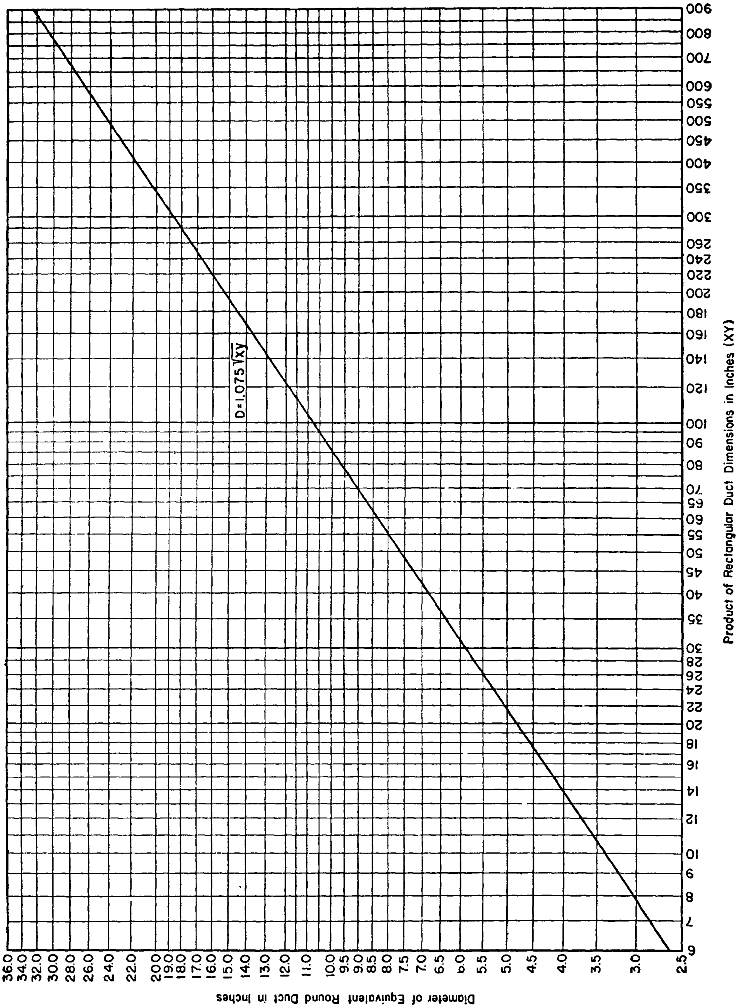


FIGURE 45. Rectangular Duct in Terms of Equivalent Round Duct

infrequently, in branch ducts for no good reason. Enlargements or contractions are necessary at standard equipment but can seldom be justified elsewhere, except at the points where branches enter main ducts. The theoretical gain in RP in well-designed transformation

pieces (enlargements) in main ducts where branches enter is offset by the turbulence of the entering air stream and can therefore be omitted from the calculations.

The energy loss or *RP* for collectors, washers, or similar equipment should be obtained from the manufacturer to be used in calculating the total *RP*. The *RP* for traps or sudden enlargements is about 1.5*VP* (see figure 38 and table 22).

TABLE 22

ENERGY LOSS IN DUCT ENLARGEMENTS AND CONTRACTIONS

Included Angle (θ) (*See Figure 44*)	*Ratio* $\frac{L}{D-d}$ (*See Figure 44*)	*Loss in Percentage of Velocity Pressure Change (VP in smaller duct minus VP in large duct)*	
		Enlargements	Contractions
5°	11.4	3	*Negligible*
10°	5.7	12	5
20°	2.8	35	6
30°	1.9	55	8
40°	1.4	75	10
50°	1.07	90	11
60°	0.87	100	13
75°	0.65	100	16
90°	0.50	100	20
120°	0.29	100	30
150°	0.13	100	45
180°		100	60

The energy loss in enlargements or contractions varies with the rate of change. If the rate of change in enlargements is very slow, theoretically there is a gain in *RP* resulting from the conversion of the *VP* to *RP*. Such gain occurs, however, only if the included angle (see figure 44) is very small which seldom occurs in local exhaust systems on the upstream side of the exhauster, and can therefore be omitted from consideration without jeopardizing the design calculations. The losses for enlargements and contractions may be read directly from table 22 for different degrees of change as determined by the use of figure 44.

(In discharge stacks it is advantageous to enlarge the diameter slowly and thereby accomplish a slight gain in *RP* proportional to the decrease in *VP*. For an included angle of 7° or less, a gain in *RP* of about 83% of the decrease in *VP* will result. To this must be added (algebraically) the *RP* caused by the duct or discharge stack.

which is determined as given under (5) above, to determine the *RP* for the stack.)

7. *Main-Duct Entrance Loss.* The final energy loss in a branch duct is that caused by its entrance into the main duct. The *RP* at

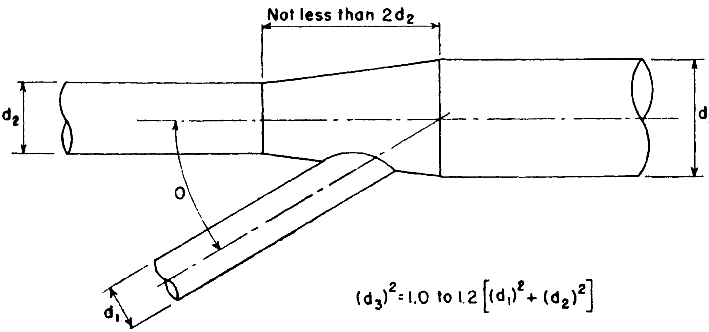


FIGURE 46. Angle of Entrance

this point varies with the angle at which the branch duct enters the main (see table 23 and figure 46). The included angle (0) should never exceed 45° and should preferably be 30° or less. The *RP* for the main-duct entrance loss may be read directly from table 23 in terms of the *VP* existing in the branch.

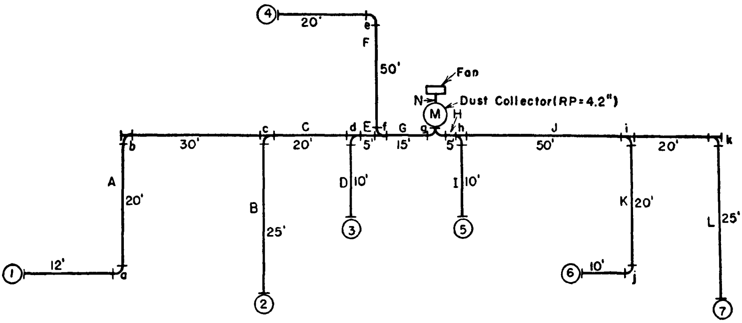
8. *The Total Pressure.* The *TP* for the branch duct is the sum of the individual *RP*'s found under 3, 5, 6, and 7 above in terms of the *VP* plus 1.0*VP* as found under 2 above. Since the *TP* of the branch where it enters the main must be the same as the *TP* existing in the

TABLE 23

RESISTANCE PRESSURE AT ENTRANCE TO MAIN DUCT IN TERMS OF VELOCITY PRESSURE IN BRANCH

Angle in Degrees at Which Branch Duct Enters Main (See Figure 46)	*Entrance Loss (RP) in Percentage of VP in the Branch*
10°	6
15°	9
20°	12
25°	15
30°	18
35°	21
40°	25
45°	28
50°	32
60°	45

main at the point where the branch enters, the *TP* for the branch in terms of its *VP* may be calculated easily and from it the actual *V*. If this is significantly greater (or smaller) than that determined under 2 (as may be the case for the branches entering the main close to the exhauster), the duct size should be recalculated to accomplish a balance. It should be noted that the only item of resistance which



Data on Hoods, Bends and Entrance Angles

HOOD	Number	1	2	3	4	5	6	7				
	Ce	0.89	0.82	0.72	0.89	0.89	0.89	0.82				
	Cfm	1000	800	600	1000	1000	1000	800				
BEND	Letter	a	b	c	d	e	f	g	h	i	j	k
	Angle	90	45	45	60	90	45	90	60	45	90	45
	Radius	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.5
DUCT ENTRANCE	Letter	b	c	d	f	h	i	k				
	Angle	45	45	30	45	30	45	45				

FIGURE 47. Schematic Exhaust System Layout

will be affected significantly in terms of the *VP* is the duct *RP*; hence, only the calculations under 4, 5, and possibly 6 above need be repeated.

The *TP* at any point in the main is the sum of the *RP*'s of all sections lying upstream therefrom plus the *TP* existing in the most remote branch.

Design Example. The calculations involved in the design of a balanced local exhaust system are best demonstrated by designing a system. In figure 47 the layout of the system to be designed is shown, including the data pertaining to the hoods, bends, and collector. The contaminant to be exhausted is a light industrial dust which will require a minimum transporting velocity of 3500 fpm. The ductwork will be of good industrial design and construction.

An inspection of the layout reveals that hoods 1 and 7 are almost equally distant from the collector; however, number 1 is slightly farther removed and will be chosen as the starting point in the calculations. The calculations for several branches will be carried forth in the steps outlined earlier for duct design.

Branch *A*

Step 1. Minimum transport velocity = 3500 fpm.
Step 2. From figure 30, $d = 7$ in., $V = 3750$ fpm, and $VP = 0.88$ in.
Step 3. Hood entrance loss $= 0.26VP$ from figure 47 and table 16.
Step 4. From table 18, the straight-duct equivalent of bends *a* and *b* is 10.8 ft.
Step 5. Total duct length is 62 (from figure 47) plus 10.8 = 72.8 ft. From table 21, $RP = 2.80VP\left(\frac{72.8}{26} = 2.80\right)$.
Step 6. No losses of this nature.
Step 7. From figure 47 and table 23, the entrance loss at point *b* is $0.28VP$.
Step 8. The *TP* at point *c* is therefore $4.34VP(1.0 + 0.26 + 2.80 + 0.28)$ which equals 3.82 in. of water.

Branch *B*

Step 1. Design $V = 3500$ fpm.
Step 2. From figure 30, $d = 6.5$ in., $V = 3500$, and $VP = 0.76$ in.
Step 3. Hood entrance loss $= 0.49VP$ from figure 47 and table 16.
Step 4. Straight-duct equivalent of bend at *c* is 3.3 ft from table 18.
Step 5. Total duct length $= 25 + 3.3 = 28.3$ ft, $RP = 1.18VP\left(\frac{28.3}{24} = 1.18\right)$.
Step 6. None.
Step 7. From figure 47 and table 23 the entrance loss at *c* is $0.28VP$.
Step 8. *TP* at point *c* is $2.95VP$ or 2.24 in. of water.

Obviously, the resistance in branch *B* is lower than in *A*, as would be expected, since the length of the duct is much less.

Redesign Branch *B*

Step 1. Same.
Step 2. From figure 30, $d = 6$ in., $V = 4100$ fpm, and $VP = 1.05$ in.
Step 3. Same.
Step 4. Equivalent length from figure 47 and table 18 is 3.0 ft.
Step 5. Total duct length from figure 47 and (4) is 28 ft.

$$RP = 1.27VP(\tfrac{28}{22} = 1.27)$$

Step 6. Same.
Step 7. Same.
Step 8. *TP* at point *c* is $3.04VP$ or 3.20 in. water gage.

If the next size smaller duct were used, the *TP* of branch *B* would be much more than for branch *A*, hence 6 in. is the proper size duct for this branch.

Therefore, $3.04VP$ in branch B must equal 3.82 in. and $VP = 1.26$ in., $V = 4495$ fpm from table 12, and $Q = 890$ cfm from figure 30.

Section C

Step 1. $V = 3500$ and $Q = 1890$.
Step 2. $d = 9\frac{1}{2}$ in., $V = 3850$, and $VP = 0.92$ from figure 30.
Step 3. None.
Step 4. None.
Step 5. $0.53VP$.
Step 6. None.
Step 7. None.
Step 8. TP at point d figure 47 equals $4.15VP \left(\frac{3.82}{0.92} = 4.15\right)$ from point c plus $0.53VP = 4.68VP$ or 4.31 in. water gage.

The foregoing calculations have been carried out step by step to show the method involved. It is apparent, however, that much paper and time would be consumed in the completion of the design example. These calculations can be speeded very much by employing a form as shown in figure 48 on which are given also the complete design calculations for the foregoing example.

To demonstrate a real shortcut made possible by this form, let us reconsider branch B which required a second set of calculations to obtain a balance. On the form shown in figure 48 the branch calculations which are recorded in columns 6, 7, and 10 are unaffected by changes in pipe sizes and may therefore be recorded permanently. Columns 4 and 5 should not be completed until the proper-size duct has been determined, and the values for columns 3 and 8 should be inserted only lightly since they are subject to change if the proper duct size has not been selected for the initial calculation. It should be noted, however, from the step by step calculations for branch B that the RP for the ductwork is affected only very little by a change in duct size.

By using the form in figure 48 we find that the TP for branch B using a 6.5-in. duct is $2.95VP(1.0 + 0.49 + 1.18 + 0.28)$. Since the TP at point c is 3.82, the VP for branch B must be $3.82/2.95 = 1.29$ in. Hence, V is approximately 4550 fpm from table 12, and, since the TP for branch B should not exceed 3.82, figure 30 indicates that a 6-in.-diameter duct is needed. Columns 3, 4, 5, 8, and 9 can now be completed, from which it is found that $3.04VP = 3.82$. Hence, $VP = 1.26$, $V = 4500$ fpm, and $Q = 890$ cfm.

Branches D and F and sections F and G are designed in similar fashion, and the results are recorded in figure 48.

The other half of the duct system requires special consideration, otherwise a balance might not be obtained at point g, requiring a series of trial calculations. The determining resistance is obviously that caused by branch L and sections J and H, since branches I and K will be calculated to balance the TP at points h and i. Hence, by

(1) Branch or Section	(2) Q in cfm	(3) d in inches	(4) V in fpm	(5) VP in inches	Pressure loss in terms of VP						(12) TP in inches of water	(13) Junction designation	Final			
					(6) Initial or VP	(7) Hood entrance	(8) Ducts and bends	(9) Collectors, traps, etc.	(10) Duct junction	(11) TP at junction			(14) VP in inches	(15) V in fpm	(16) Q in cfm	(17) TP in inches
A	1000	7	3750	0.88	1.0	0.26	2.80	0	0.28	4.34	3.82	c	0.88	3750	1000	3.82
B	800	6	4100	1.05	1.0	0.49	1.27	0	0.28	3.04	3.20	c	1.26	4500	890	3.82
C	1890	$9\frac{1}{2}$	3850	0.92	4.15	0	0.53	0	0	4.68	4.31	d	0.92	3850	1890	4.31
D	600	5	4400	1.21	1.0	0.93	0.73	0	0.18	2.84	3.44	d	1.52	4950	675	4.31
E	2565	$11\frac{1}{2}$	3550	0.78	5.53	0	0.11	0	0	5.64	4.40	f	0.78	3550	2565	4.40
F	1000	7	3750	0.88	1.0	0.26	3.10	0	0.28	4.64	4.08	f	0.95	3900	1040	4.40
G	3605	13	3900	0.95	4.63	0	0.55	0	0	5.18	4.92	g	0.95	3900	3605	4.92
L	800	$6\frac{1}{2}$	3475	0.75	1.0	0.49	2.12	0	0.28	3.89	2.92	i	0.81	3600	830	3.15
K	1000	7	3750	0.88	1.0	0.26	1.57	0	0.28	3.11	2.74	i	1.01	4025	1075	3.15
J	1905	$9\frac{1}{2}$	3875	0.94	3.35	0	1.31	0	0	4.66	4.38	h	0.94	3875	1905	4.38
I	1000	$5\frac{1}{2}$	6050	2.28	1.0	0.26	0.68	0	0.18	2.12	4.84	h	2.06	5750	950	4.38
H	2855	11	4325	1.17	3.74	0	0.39	0	0	4.13	4.84	g	1.19	4375	2880	4.92
M	6460										4.20					9.12
N	6460	18	3650	0.83	11.0	0	0.06	0	0	11.06	9.2		0.83	3650	6460	9.2

FIGURE 48. Convenient Form for Making Calculations by Balanced-System Method

listing the branches and sections on the tabulating form and inserting the known values in columns 6, 7, and 10 (from figure 47) and the approximate values in columns 3 and 8, the TP at point g for branch L and sections H and J is determined in terms of the VP. The value of VP may then be determined by dividing into the TP at point g for the other section, namely, 4.92. In the calculation of this example, for instance, the TP at g was found to be $5.88VP$. Thus the design velocity is 3670. This value is quite close to the minimum

transporting velocity only because the duct system is well balanced on both sides of the junction at g. If only one short duct were on the right side of the junction, the required V would be much higher. The final calculations are then carried out by starting with the most remote branch, namely L.

Another point of interest in the design of the second half of the duct system arose in the calculations pertaining to branch L. If a 6-in. duct had been selected to obtain a transporting velocity above 3500 fpm, the TP at point i would have been very high since, at 800 cfm, V would be about 4100 fpm. This high TP at point i would then be carried through to point g since little reduction in TP over that estimated for sections H and J can be effected owing to the low design velocity as compared to the lower limit of the transporting velocity. The solution lay in increasing Q in branch L slightly to obtain a duct velocity above the minimum transporting velocity. A velocity of 3600 fpm was selected since (*a*) it was close to the calculated required velocity of 3670 fpm, (*b*) it was above the minimum transporting velocity, and (*c*) it required only a small increase of Q.

This point should be borne in mind in the design of the first two branches of any system. If the design value of Q is adhered to strictly for the design of the most remote branch, a high V may result, and the TP at the point of junction would be needlessly high, resulting in a greater power consumption than necessary. Whereas, if Q is increased slightly so that the next larger standard duct can be used and V kept at a value only slightly above the minimum transporting velocity, the TP at the intersection will be much lower, resulting in a more efficient design.

The exhauster must be chosen on the basis of the volume of air flow and final TP shown in figure 48 minus the VP at the fan inlet. (The discharge duct or stack from the fan was not included in this calculation. Its RP should be added to the TP shown in the table to obtain the value to be used for fan selection.) Owing to leakage and reduction in efficiency as the system becomes worn it is advisable to increase Q as calculated by about 20% to insure satisfactory performance after considerable use. Consequently, a fan would be selected to handle 8100 cfm at a total pressure of 9.2 in. of water (plus that for a suitable discharge stack) minus one VP at the fan inlet or 0.83 if the inlet diameter is 18 in. The brake horsepower (BHP) of the fan motor would be calculated by the following equation:

$$BHP = \frac{Q \times TP}{6356 \times ME} \tag{20}$$

where BHP = brake horsepower of fan motor.
Q = quantity of air in cubic feet per minute (8100 for this example).
TP = total pressure in inches of water of duct system including the discharge stack.
ME = the mechanical efficiency of the fan which can be obtained from the manufacturer.

The design of a local exhaust system includes also the selection of a suitable fan and may include the selection of a collector. The characteristics of these devices will be discussed in Chapters VIII and VII, respectively.

TRANSPORT-VELOCITY DESIGN

The second common (and probably most popular) design procedure is that based on the transport velocity only. The system is balanced by means of blast gates located in the branches close to the main duct. This design procedure is relatively simple and has much to recommend it. The blast gates should, however, be bolted, welded, or otherwise locked into position, after the system has been balanced carefully, to prevent being changed by the workers.

Most of the design calculations are similar to those discussed previously, except that no attempt is made to balance the system through the selection of proper duct sizes. The sizes of all branch and main ducts are determined by equation 11 or 12 or figure 6. The governing resistance is that of the one having the greatest pressure loss, usually the longest one, the flow through the other branches being balanced by means of the blast gates.

Design Example. The calculations involved can be demonstrated best by an example. The same system as designed by the other method and, as shown in figure 47, will be selected. The results are recorded in a convenient form as shown in figure 49.

Branch A

Step 1. Transport velocity = 3500 fpm and Q = 1000 cfm.

Step 2. From figure 30 (or from a combination of equations 11 and 12; tables 12, 13, and 14; and figure 6), d = 7 in., V = 3750 fpm, and VP = 0.88 in. of water.

Step 3. Hood entrance loss = $0.26VP$ (from figure 47 and table 16) or 0.23 in. of water.

Step 4. From table 18, the straight-duct equivalent of bends *a* and *b* is 10.8 ft.

Step 5. Total duct length is 62 ft (from figure 47) plus 10.8 ft. From table 21, $RP = 2.80\ VP$ or 2.46 in. (NOTE. Some designers prefer a friction

					Pressure loss in inches H_2O							Final			
(1) Branch or Section	(2) "Q" in cfm	(3) "V" in fpm (design)	(4) "d" in inches	(5) "V" in fpm (actual)	(6) VP in inches	(7) Hood entrance	(8) Ducts and bends	(9) Collectors, traps, etc.	(10) Duct junction	(11) TP at junction	(12) Junction designation	(13) "V" in fpm	(14) VP in inches	(15) "Q" in cfm	(16) TP in inches
A	1000	3500	7	3750	0.88	0.23	2.46	0	0.25	3.82	c	3750	0.88	1000	3.82
B	800	3500	$6\frac{1}{2}$	3470	0.75	0.37	0.89	0	0.21	2.22	c				
C	1800	3500	$9\frac{1}{2}$	3660	0.84	0	0.44	0	0	4.26	d	3660	0.84	1800	4.26
D	600	3500	$5\frac{1}{2}$	3630	0.82	0.76	0.56	0	0.15	2.29	d				
E	2400	3500	11	3640	0.83	0	0.09	0	0	4.35	f	3640	0.83	2400	4.35
F	1000	3500	7	3750	0.88	0.23	2.72	0	0.25	4.08	f				
G	3400	3500	13	3690	0.85	0	0.47	0	0	4.82	g	3690	0.85	3400	4.82
L	800	3500	$6\frac{1}{2}$	3475	0.75	0.37	1.51	0	0.21	2.84	i	3475	0.75	800	2.84
K	1000	3500	7	3740	0.88	0.23	1.38	0	0.25	2.74	i				
J	1800	3500	$9\frac{1}{2}$	3660	0.84	0	1.11	0	0	3.95	h	3660	0.84	1800	3.95
I	1000	3500	7	3740	0.88	0.23	0.50	0	0.16	1.77	h				
H	2800	3500	12	3570	0.80	0	0.30	0	0	4.25	g	3570	0.80	2800	4.25
M	6200							4.20							9.02
N	6200	3500	18	3510	0.75	0	0.05	0	0	9.07		3510	0.75	6200	9.07

FIGURE 49. Convenient Form for Making Calculations by Transport Velocity Method

chart as shown in figure 50 for this computation. The data in figure 50, however, represent a value for C in equation 17 of 50 instead of 55 as used in table 21. The friction chart will, therefore, give a slightly different result, the difference being too small to be of consequence.)

Step 6. No other energy losses except main-duct entrance.

Step 7. From figure 47 and table 23, the entrance loss at point *b* is $0.28VP$ or 0.25 in.

Step 8. The TP at point c is therefore $0.88 + 0.23 + 2.46 + 0.25 = 3.82$ in. of water.

Branch B

Step 1. Transport velocity = 3500 fpm and $Q = 800$ cfm.

Step 2. From figure 30 (or from a combination of equations 11 and 12; tables 12, 13, and 14; and figure 6), $d = 6.5$ in., $V = 3470$ fpm, and $VP = 0.75$ in.

Step 3. Hood entrance loss = $0.49VP$ (from figure 47 and table 16) or 0.37 in.

Step 4. Straight-duct equivalent of bend at c is 3.3 ft from table 18.

Step 5. Total duct length = 25 ft from figure 47 plus 3.3 for bends or 28.3 ft. RP from table 21 equals $1.18VP$ or 0.89 in.

Step 6. No other energy losses except main-duct entrance.

Step 7. From figure 47 and table 23, the entrance loss at c is $0.28VP$ or 0.21 in.

Step 8. TP at point c is therefore $0.75 + 0.37 + 0.89 + 0.21 = 2.22$ in.

Obviously, a blast gate will be needed in branch B to increase its total resistance to 3.82 in. to balance branch A.

The calculations for the other branches and for sections of the main will not be carried out in detail. They may be followed conveniently by reference to figure 49. It is apparent from this figure that the governing branch and section is $ACEG$. Blast gates for balancing will be needed in branches B, D, F, I, and K, and in section H. Also a study of figures 48 and 49 will show that the only significant difference between the two designs is the smaller sizes which may be used for some of the duct branches by the balanced-system method than if the balance is obtained by blast gates.

Effect of High Temperature and Elevation. The data in the foregoing tables and figures are based on an air density of 0.075 lb per cubic foot (70° F dry air at 29.92 in. of mercury barometric pressure). Where considerable variation from these conditions occurs, the change in air density must be considered. Usually corrections are not needed for temperatures under 100° F and 1500 ft elevation.

It must be remembered that a centrifugal fan connected to a given system will exhaust essentially the same *volume* regardless of air density. The *weight* of air moved, however, will depend upon the density, as will the pressure developed and the horsepower consumed. Assume, for example, a fan in a given local exhaust system which is capable of moving 10,000 cfm of air at standard conditions through the system. If the air is heated to 600° F after it enters the hoods the volume of air exhausted is 10,000 cfm at 600° F. This quantity of air has a volume of 5000 cfm at 70° F and would result in a reduction of 50% in the rate of air inflow at the hoods. In like manner, the density of the air at 5500 feet above sea level is reduced to 81% of the weight at standard conditions.

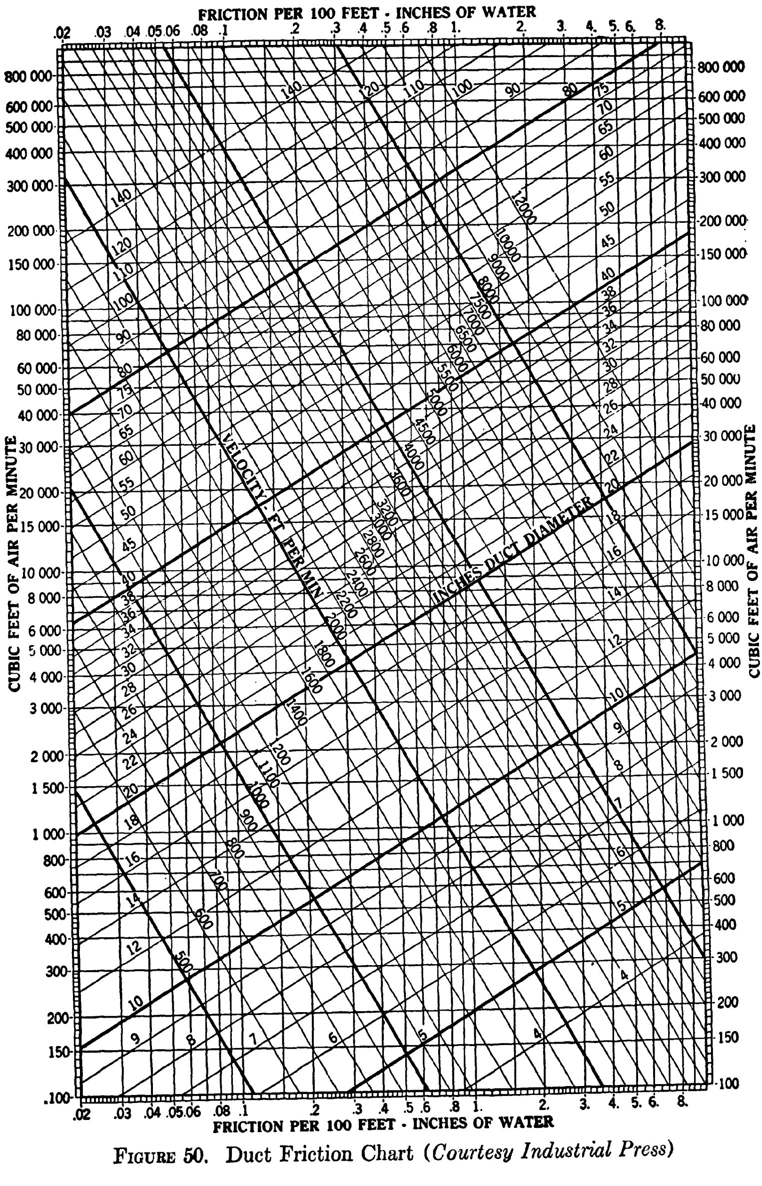


FIGURE 50. Duct Friction Chart (*Courtesy Industrial Press*)

To correct for high temperatures or elevations, increase the exhaust volumes by the reciprocal of the density to keep the same weight of air flowing into the hoods. To select the exhauster, compute the branch- and main-duct sizes and the pressure losses as if the corrected volumes were standard air. This procedure permits selecting the proper-sized exhauster and revolutions per minute. The horsepower and actual pressure losses of the system, on the other hand, will decrease directly as the air density decreases. Tables 24 and 25 give relative density factors for temperature and elevation changes which may be used conveniently in making corrections for density.

TABLE 24

AIR DENSITY AT DIFFERENT TEMPERATURES

Temperature Degrees F	*Weight of Air in Pounds per Cubic Foot*	*Density Factor*
0	0.0864	1.152
70	0.0749	1.000
100	0.0709	0.946
150	0.0651	0.869
200	0.0602	0.803
250	0.0560	0.747
300	0.0522	0.697
350	0.0490	0.654
400	0.0462	0.616
450	0.0436	0.582
500	0.0414	0.552
550	0.0393	0.525
600	0.0375	0.500
650	0.0358	0.477
700	0.0342	0.457
750	0.0328	0.438
800	0.0315	0.421
850	0.0303	0.404
900	0.0292	0.390
950	0.0282	0.376
1000	0.0272	0.363

Practical Duct Design and Construction Considerations. With the duct sizes as determined earlier, the sheet-metal shop or a sheet-metal contractor can install the required ductwork. Proper installation is essential to satisfactory operation. Good construction and installation practice is as follows: [75]

a. All work should be constructed of new materials. Interior surfaces of all ducts should be smooth and free from obstructions—joints to be soldered air-tight. Other sealing materials may be used where soldering is impractical.

b. Ducts should be constructed of galvanized sheet steel except where the presence of corrosive gases or mists, temperatures over 400° F, or other factors make such material impractical. Data on different duct material for a variety of acid mists may be found in table 26. Corrosion-resisting paint is sometimes satisfactory for the interior surfaces.

TABLE 25

AIR DENSITY AT DIFFERENT ALTITUDES

Elevation in Feet Above Sea Level	*Weight of Air in Pounds per Cubic Foot*	*Density Factor*
0	0.0749	1.000
500	0.0735	0.981
1,000	0.0721	0.962
1,500	0.0707	0.944
2,000	0.0694	0.926
2,500	0.0681	0.909
3,000	0.0668	0.891
3,500	0.0655	0.874
4,000	0.0643	0.858
4,500	0.0631	0.842
5,000	0.0619	0.826
5,500	0.0607	0.810
6,000	0.0596	0.795
6,500	0.0585	0.780
7,000	0.0574	0.766
7,500	0.0563	0.751
8,000	0.0552	0.737
8,500	0.0542	0.723
9,000	0.0532	0.710
9,500	0.0522	0.697
10,000	0.0514	0.685

c. For the ductwork of most systems the minimum metal thickness should be as given in table 27.

d. For highly abrasive contaminants or high concentrations of moderately abrasive contaminants, straight ducts should be constructed of metal at least two gages heavier than given in table 27.

e. All bends should be at least two gages heavier than straight ducts of the same diameter.

f. Hoods should be at least two gages heavier than the straight section of the connecting branch.

g. Longitudinal joints of the ducts should be lapped and riveted or spot welded on 3-in. centers or less.

TABLE 26

Corrosion-Resisting Materials for Exhaust Systems [a]

Material	Acid [b]							
	Acetic	Chromic	Hydrochloric	Hydrofluoric	Nitric	Phosphoric	Sulfurous	Sulfuric
	Dil./Conc.	Dil./Conc.	Dil./Conc.	Dil./Conc.	Dil./Conc.	Dil./Conc.	Dil./Conc.	Dil./Conc.
Metals								
Aluminum	Good	Fair	Poor	No Data	Poor/Good	Poor	Poor	Poor
Magnesium and alloys	No Data	Good/Poor	No Data	Poor/Good	No Data	No Data	No Data	No Data
Lead and lead-coated	Poor	Good	Poor	Poor	Poor	Poor	Good	Good/Poor
Molybdenum alloy (60Ni-20Mo-20Fe)	Good	No Data	Fair	No Data	Poor	Poor	No Data	Good
Mohel metal	Fair	Poor	Fair/Poor	Good [d]	Fair/Poor	Fair	Poor	Good [e]/Poor
Bronze	Poor						Good	
Silicon iron	Fair/Good	No Data	Fair	Poor	Good	Good	No Data	Good
Stainless steel [c] (18 Cr-8Ni)	Good	Good	Poor	No Data	Good	Poor	Good	Poor/Good [e]
Enameled steel	No Data	No Data	Good	Poor	Good	Poor	No Data	Good
Miscellaneous								
Rubber					Poor			Poor
Asbestos comp	Good except against strong acids and alkalies							
Wood	Some woods are decomposed or softened faster than others							
Plastics	In general, plastics resist weak acids and are decomposed by concentrated acid							

Notes

a. "Standard Practice Sheet 115," Division of Industrial Hygiene, New York State Labor Department.
b. Acid mists in air are more corrosive than when liquid in a storage tank. Galvanized iron not resistant to acid.
c. Stainless steel of (24Cr-10Ni) fairly resistant at low temperature for HCl and H_3PO_4.
d. Under most conditions.
e. At room temperatures.

h. Girth joints of ducts should be made with the lap in the direction of air flow. A 1-in. lap should be used for ducts of 19 in. diameter and less and a 1¼-in. lap for larger ducts.

i. All bends should have a centerline radius of curvature of 2½ pipe diameters wherever possible, but the centerline radius of curvature should never be less than 1½ pipe diameters. Large-radius bends are essential for high concentrations of highly abrasive dusts. Elbows (90° bends) not over 6 in. in diameter should be constructed of at least five sections, and elbows of larger-diameter ducts should be constructed of at least seven sections. Other bends are sectioned in proportion.

j. Hoods should be free from sharp edges or burrs and should be reinforced to obtain satisfactory stiffness.

k. The duct should be connected to the exhauster inlet by means of a split-sleeve drawband one pipe diameter (but not less than 5 in.) long.

TABLE 27

SHEET-METAL THICKNESS FOR DIFFERENT-SIZED DUCTS

Diameter of Straight Duct in Inches	*U. S. Gage Number*	*Sheet-Metal Thickness in Inches*
8 and less	22	0.0306
8½–18	20	0.0368
18½–30	18	0.0490
Over 30	16	0.0613

l. Transitions in mains and submains should be tapered. The taper should be about 5 in. long for each inch diameter change (see table 22 and figures 44 and 46).

m. The branches should enter the main near the large end of the transition and at an angle not to exceed 45°—30° or less preferred (see figure 46). Connection to the main should be made at the top or on the sides, not on the bottom. Branch connections should be staggered; two branches should never enter the main at diametrically opposite points.

n. Dead-end caps should be provided on mains and submains about 6 in. from the last branch.

o. Cleanouts should be provided every 10 or 12 ft and near each bend or duct.

p. The duct should be so supported that no weight is transferred to the connecting equipment and that it will not fall if completely loaded with the contaminant. The recommended maximum supporting interval is 12 ft for ducts 8 in. or smaller and 20 ft for larger ducts.

q. There should be a minimum clearance of 6 in. between the ducts and the ceiling, wall, or floor.

r. Blast gates should be of sturdy construction, and a positive means should be provided for locking or bolting them in position after the system has been balanced.

s. Round ducts should be used wherever possible. If clearances prevent the use of round ducts, rectangular ducts as nearly square as possible may be used. Weight of metal, lap, and other construction details are to be equal to those of

round ducts whose diameter is the same as the longest side of the rectangular duct.

t. Where necessary, weather caps as detailed in figure 51 should be used.

Many hoods are of the "open-and-shut" type (on melt ovens, mixing and reactor kettles, and the like). Such hoods will throw

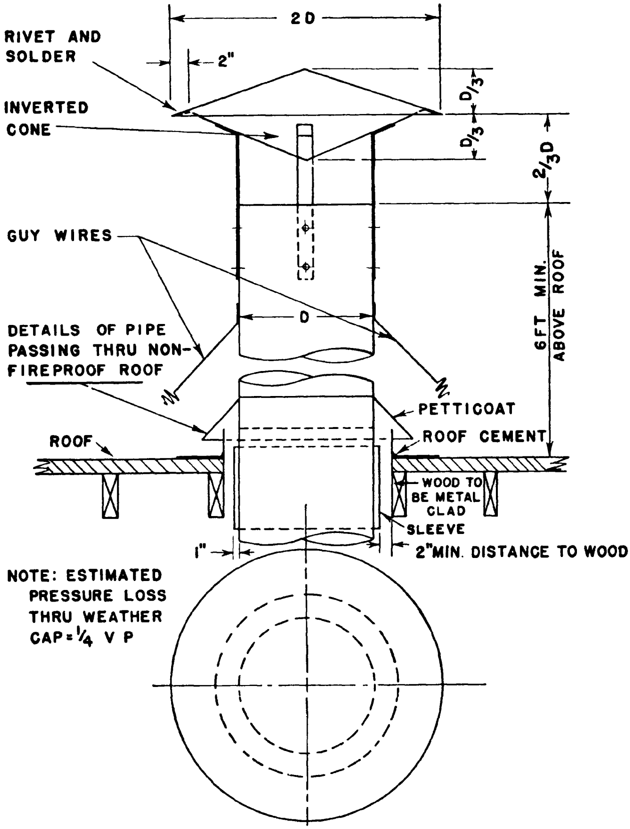


FIGURE 51. Weather-Cap Design (*Courtesy N. Y. State Labor Dept.*)

the entire system out of kilter unless properly covered in the design since little or no air is entering the hood when closed, and considerable air flow is needed when the hood is open. This difficulty can be overcome by using a streamlined Y to connect the hood with the branch and installing a good barometric damper in the open leg of the Y. With such an arrangement, and with the damper properly balanced, most of the air will enter through the hood when it is

open, and through the damper when the hood is closed. The proper transporting velocity will then be maintained in all ducts, the general ventilation of the room afforded by the local exhaust branch will be in operation at all times, and any collector which may be located in this branch will operate satisfactorily.

Considerable practical data on the required rates of air flow and transporting velocities for a variety of operations may be found in Table E in the Appendix.

CHAPTER VII

COLLECTORS

Even though this chapter is devoted to a discussion of the devices employed for the removal of the contaminants from the air exhausted by ventilating systems, particularly local exhaust systems, a substantial percentage of such systems do not contain collectors of any kind; the contaminated air is merely discharged to the outside. In general, collectors are used only for one or more of the following reasons:

1. To recover valuable material.
2. To eliminate or prevent a neighborhood nuisance.
3. To eliminate or prevent a health hazard.

If none of the foregoing circumstances are present, the contaminated air may be discharged to the outside at a point where it will not re-enter any building in sufficient quantity to create a nuisance or health hazard. Not infrequently, however, collectors are omitted from local exhaust systems where they are needed. This is not good engineering practice and should be prevented as much as possible.

In some instances also, collectors are not installed simply because suitable devices are not available for removal of the contaminant, either because of its nature or its quantity or both.[76] In such instances, the discharge is usually accomplished at a sufficiently high point to effect adequate dilution and "carry" before it settles to the earth to prevent a nuisance or health hazard. Information and data which are useful in determining minimum stack heights are contained in references 76, 77, and 78.

A distinction must be made between "air filters" or "air cleaners" and "collectors." This differentiation is not clear in the usual terminology but rather by use of equipment. Air cleaners used for removing smoke and dirt from air supplied to public buildings, domestic dwellings, and some industries operate on the same principles as the collectors used for removing atmospheric contaminants from air exhausted by process ventilating or local exhaust systems. They

are similar to collectors in many respects and differ largely in that cleaners are designed to remove a small quantity (low loading) of smoke or dirt from a large volume of air with a very low pressure loss across the cleaner, while collectors are designed to remove a high dust, fume, or mist load from a relatively small volume of air and with little to considerable pressure loss across the cleaning equipment. Since industrial hygiene engineers seldom are called upon for advice on air cleaning equipment of the type used for ventilating or air conditioning public buildings, domestic dwellings, and the like, this type of collector will not be discussed in this book. Information on the subject may be found in reference 2, and in many books on ventilation and air conditioning.

A second type of air cleaners which industrial hygiene engineers are rarely concerned with but which, through similarity of terminology and method of operation, may cause confusion are cleaners for compressors and internal-combustion engines. Air cleaners of this type, likewise, will not be covered in this book; data on them may be found in reference 79.

Characteristics Which Are Desirable in Collectors. No single type of collector embodies all virtues. According to Alden[80] the following characteristics are desirable in air-cleaning plants for process ventilating or local exhaust systems:

1. The concentration of the contaminant in the cleaned air should be below the predetermined permissible limit.
2. The collector should retain its cleaning efficiency throughout its life.
3. The cleaning efficiency should be substantially constant throughout its daily operating cycle.
4. The cleaning efficiency should be nearly independent of the rate of air flow and the concentration of the contaminant in the entering air.
5. The collector should not require shutdowns for cleaning or routine maintenance during the normal working hours.
6. Normal maintenance and periodic disposal of collected dust should introduce no new health or fire hazards.
7. The collector should embody the usual elements of low cost, durability, minimum maintenance, minimum space, and other factors which purchasers expect of all factory equipment.

The cleaning efficiency is usually expressed as the percentage by weight of the contaminant reaching the collector which is removed

by it. This index is satisfactory for collectors used to recover valuable materials. The increased cost of the more effective collectors can be balanced against the increased amount of material recovered. Such installations, however, rarely enter the purview of the industrial health engineer. His is the task of determining what collector to install for the elimination or prevention of a nuisance or health hazard. From this viewpoint, percentage collecting efficiency, particularly on a weight basis, has little meaning since the greater the entering load the greater will be the concentration of the contaminant in the discharged air for a given collecting efficiency, and one 10-micron particle of a fibrosis-producing dust is apparently no more harmful than a 1-micron particle, even though it weighs 1000 times as much.[81, 82, 83] The only satisfactory measure of the adequacy of a cleaning device from the industrial health standpoint is the actual concentration of the contaminant in the discharged air.

Factories or industries which are not located in or near residential areas may discharge considerable dust, fume, mist, smoke, gas, or vapor to the outside without creating a nuisance or health hazard. For such plants, removal of part of the contaminant may be all that is needed as long as the exhausted air is discharged at a suitable point. On the other hand, some plant managers, particularly in the northern states, want to clean and recirculate the exhausted air to conserve heat. This is a logical desire but is fraught with danger, particularly if the contaminant is a toxic material, such as lead or silica. Some state occupational disease control codes forbid this practice entirely due largely to the fact that collectors are not foolproof nor are they free from operating "bugs." It is obvious that a serious condition would exist if the collector efficiency were to drop considerably below normal while the air is being recirculated. Nevertheless, heating make-up air in northern climates where large quantities are involved is expensive (approximately $20.00 to $30.00 per year per 1000 cfm, not including equipment depreciation), and it is the opinion of the author that in the not far distant future considerable process ventilation air will be cleaned thoroughly and safely and recirculated, particularly from processes which produce only relatively nontoxic contaminants.

Most collectors available today are intended to remove particulate matter (dusts, fumes, smokes, and mists) from the exhausted air, not gases or vapors. Some of these devices, such as wet collectors (scrubbers, trickling towers, etc.) and activated carbon filters,

remove gases and vapors, although not too effectively in most instances. They have not been used widely for this purpose up to the present; the usual procedure is to use discharge stacks of suitable height.

Types of Collectors. Collectors which are of most interest to industrial hygiene engineers may be divided into five main groups, largely on a functional basis, but they are also of importance as regards the particle size of contaminant which each is particularly adapted to remove.

1. Settling chambers.
2. Inertial or centrifugal collectors.
3. Filters.
4. Wet collectors.
5. Electrostatic precipitators.

Not infrequently the air-cleaning plant will consist of more than one type of collector selected to accomplish complementary functions. The first or primary collector is usually a settling chamber or cyclone which removes the bulk of the material by weight and particularly the larger-sized group of particles. The second, usually a filter or electrostatic precipitator, is intended to remove much of the smaller-sized materials not removed by the primary separator. There are also some collectors, such as centrifugal air washers, which combine the cleaning principles of two of the above groups.

Although the different types of collectors are not truly selective separators, each type has a minimum particle size beyond which its collecting efficiency is too low in general to be of practical value. The suggested minimum particle size groups for the different collector types are given in table 28. It must be borne in mind, of course, that the data given in the table do not apply to all commercial collectors in each group. Some few collectors of each type may be considerably better filters, and some few worse, than indicated in the table.

Settling chambers, often called gravity separators, operate on the principle of reducing the air velocity in the chamber sufficiently low and for the required time to permit all particles above the minimum size group to settle out (see figure 52). Collectors of this type are capable, theoretically, of removing air-borne particulate matter down to 5 or 10 microns in size but are not practical for removing such small particles because of the extremely large size required. The usual velocity through settling chambers is between 100 and

250 fpm, although about 60 fpm is preferred.[84] The second important factor in the collector design is its length since the minimum-sized particle which is to be removed must have time to reach the

TABLE 28

SUGGESTED MINIMUM PARTICLE SIZE GROUPS FOR DIFFERENT COLLECTORS

Type of Collector	*Minimum Particle Size (microns)*
Settling chamber	100–200
Inertial collector	50–200
Centrifugal collector	
Cyclone—large diameter	40–60
Cyclone—small diameter	20–30
Fan type	15–30
Filter	0.5–2.0
Wet collector	1.0–2.0
Electrostatic precipitator	0.001–1.0

bottom of the collector before it reaches the outlet end of it where the air velocity increases, preventing further settling. This suggests that the chamber should be reasonably shallow so that the required distance of fall of the particle is not great.

The rate of fall in air of spherical particles of a material having the same specific gravity as silica (2.65) are given in table 29.

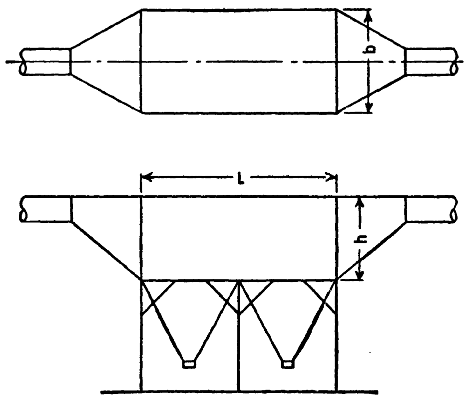


FIGURE 52. Settling Chamber (*Reprinted by permission from "Industrial Dust," by Drinker and Hatch, Copyrighted, 1936, by the McGraw-Hill Book Company, Inc.*)

More data of this same type, but for materials having a specific gravity of 1.0, are given in Figure I in the Appendix. Since the rate of fall for all particles covered by Stoke's law is essentially propor-

tional to the specific gravity, the rate of fall for any particle can be determined very readily from Figure I. It must be noted that these settling rates are for spherical particles in still air. It has been found that in practice the true settling rate is about half that given in table 29 and Figure I of the Appendix. Hence, for silica dust, for example, the ratios of the settling chamber height to length

TABLE 29

SETTLING RATE OF SPHERICAL PARTICLES (SPECIFIC GRAVITY 2.65) IN AIR

Particle Diameter (microns)	*Settling Rate (feet per minute)*
200	640
150	360
100	160
50	40
25	10
10	1.6

for an air velocity through it of 60 fpm for different-sized particles are given in table 30. It is apparent from this table that the height would equal the length for particles slightly less than 100 microns (87 microns). At the more common chamber velocity of about 200 fpm, the height would equal the length for particles of 150 microns. For considerably smaller particles the length becomes excessive and

TABLE 30

RATIO OF CHAMBER HEIGHT TO LENGTH NECESSARY TO CAPTURE SILICA PARTICLES (SPECIFIC GRAVITY 2.65) WHEN AIR VELOCITY IN CHAMBER IS 60 FPM

Particle Size (microns)	*Ratio* $\left\{\frac{\textit{Height}}{\textit{Length}}\right.$
200	5.33
150	3.00
100	1.33
50	0.33
25	0.085
10	0.013

impractical, although an attempt has been made by one manufacturer to overcome this difficulty by constructing the collector interior of a series of horizontal plates not far apart. This collector has the objection of being difficult to clean.

An important feature in the design of settling chambers for satisfactory operation is the entrance and exit. Since turbulence within the unit should be at a minimum, the inlet and outlet should be so

shaped as to produce a uniform velocity over the entire area (see figure 52). Also, straightening devices may be helpful.

Another common type of settling chamber which combines some inertial effect is shown in figure 53.

Settling chambers alone are satisfactory if the bulk of the air-borne material is of large size and if there is no harm or objection to discharging the "fines" outside. The greatest need for such collectors, however, is as preliminary separators in conjunction with more efficient collectors to remove the bulk of the material by weight

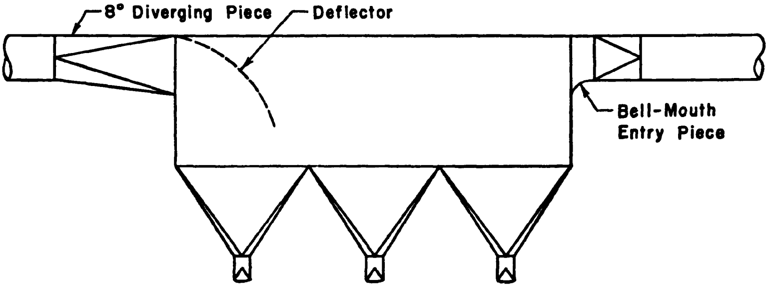


FIGURE 53. Settling Chamber with Deflector (*Courtesy Kravath*)

and thereby improve the over-all operation of the secondary collector.

The energy loss through settling chambers of the usual design is in the order of 1.5 to 2.0 pipe velocity pressures; that is, 1.5 to 2.0 times the velocity pressure in the outlet pipe. By good design the energy loss may be reduced to less than 1.0 velocity pressure.

Inertial or *centrifugal collectors* include three general and more or less distinct groups: the simple inertia separator or trap as shown in figures 54 and 55, the cyclone as illustrated in figure 56, and the so-called "dynamic precipitator" shown in figure 60.

Inertial or centrifugal collectors operate on the principle that dust or other particulate matter, owing to its greater density, offers more resistance to a change in direction than does air. In the collector, the air is forced to change direction rapidly, and the contaminant is literally thrown out of the air by its own momentum. The contaminant then enters a relatively still air zone in which it settles out. Since some of the air also enters and leaves the "still-air zone," considerable turbulence exists, and the contaminant does not settle as rapidly or consistently as it would otherwise.

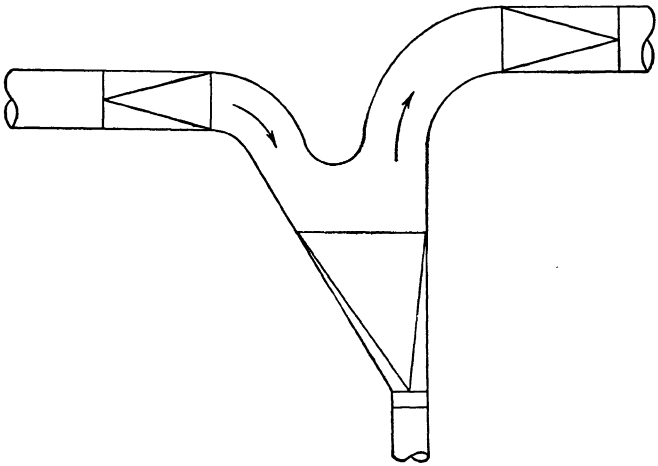


FIGURE 54. Inertial Trap (*Courtesy "Design of Industrial Exhaust Systems"*)

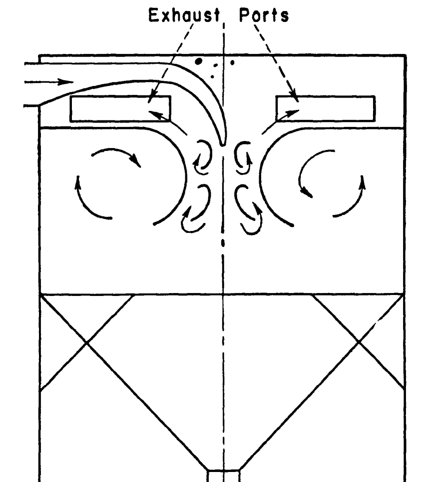
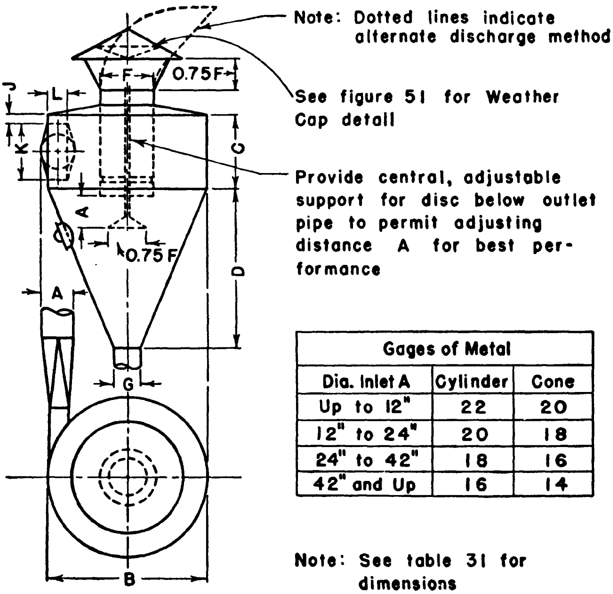


FIGURE 55. Inertial Separator (*Reprinted by permission from "Industrial Dust," by Drinker and Hatch, Copyrighted, 1936, by the McGraw-Hill Book Company, Inc.*)

Theoretical considerations are of little value for designing *simple inertial separators.* Experiments need to be conducted on full-scale models of such units to decide what will be the best design for a given operation.

Cyclone separators are probably the most common type of collector. They are used widely as preliminary separators and as the



Gages of Metal		
Dia. Inlet A	Cylinder	Cone
Up to 12"	22	20
12" to 24"	20	18
24" to 42"	18	16
42" and Up	16	14

FIGURE 56. Standard Cyclone Details

only collector in dust control systems handling a large amount of large-sized dust which is relatively nontoxic, such as wood dust.

In cyclones, the operating principles of settling chambers and inertial separators are combined. The force which causes the particles to move to the wall of the cyclone is centrifugal force, which varies with the size of the cyclone and the volume of air handled. In practice it exceeds substantially the force of gravity which is operative in settling chambers. The separating ability (termed separation factor or separation coefficient) is a function of the air velocity and the cyclone diameter as defined in the following:

$$S = \frac{V^2}{gr} \tag{21}$$

where S = separation coefficient.
V = tangential velocity in feet per second.
g = acceleration due to gravity.
r = radius of rotation in feet.

It becomes obvious from the foregoing that the separation coefficient may be increased very readily by decreasing the cyclone diameter without increasing the pressure loss substantially. Hence, from an operational standpoint, it is advisable to use a number of small diameter cyclones in parallel rather than to employ a single large diameter unit. Not only will the cleaning efficiency be higher for the same power consumption, but collector units may be cut in and out as needed to maintain a fairly uniform velocity through each. By so doing, a high collecting efficiency can be maintained which is not possible with a single large unit.

The large cyclone (body diameter 3½ to 6 times the inlet duct diameter) is the more common type. It handles a larger volume of air per dollar of first cost than any other collector. The shape and dimensions of the conventional design of large cyclones are given in figure 56 and table 31, the dimensions in the table being keyed to the figure.

The pressure loss through cyclones varies very much from unit to unit, frequently because of the "adjusting tinkering" of erecting personnel. Examples are reported where the loss through one collector was 3½ times that of another cyclone installed in the same plant and engineered by the same firm.[80] In simple exhaust systems the cyclone resistance is often the largest single item in the total resistance of the system, sometimes contributing 80% of the total loss. Yet it is not unusual to find in the literature statements to the effect that the resistance of a well-designed cyclone is about one velocity head in the inlet pipe. Many cyclones do have resistances in the order of one inlet duct velocity pressure or less. Nevertheless, resistances ranging from 0.25 to 7 velocity heads have been reported. The actual loss should be ascertained from the manufacturer for use in the design of an exhaust system, and if of "home-made" construction, it should be determined before the total loss in the system is computed.

An important source of resistance in a cyclone is the interference of the revolving air stream with the air stream entering the collector from the inlet duct. This source of resistance may be eliminated

by means of a helical top, as shown in figure 57, or by an inlet deflector, as shown in figure 58.

TABLE 31

Dimensions of Different-Sized Cyclone Dust Collectors

(Letters keyed to figure 56)

Fan Outlet Diameter (inches)	Fan Outlet Area (square inches)	Size of Collector Openings: Inlet Size (inches)		Inlet Area (square inches)	Air Outlet Diameter (inches)	Air Outlet Area (square inches)	Dust Outlet Diameter (inches)	Collector Dimensions: Cylinder Outside Diameter (inches)	Cylinder Height (inches)	Cone Length (inches)	Shipping Weight Approximately (pounds)
A	—	*L*	*K*	—	*F*	—	*G*	*B*	*C*	*D*	—
5	20	2½	9	23	8½	56	3	29½	14	26½	70
6	28	3	10½	32	10	78	4	35½	15½	32½	100
7 *or* 8	38 *or* 50	3½	13	47	13	132	6	41½	18½	37½	140
9	63	4½	16	72	15	176	6	47½	21	43½	175
10	78	5	18	90	17	227	6	53½	23	50	245
11 *or* 12	95 *or* 113	5½	21	115	20	314	10	59½	26	56	315
13 *or* 14	133 *or* 154	6½	24	156	23½	433	10	65½	29	61½	395
15	177	7	27	189	26	531	10	71½	32	67½	490
16 *or* 17	201 *or* 227	8	30	240	28	615	10	77½	35	72½	575
18	254	8½	32	272	31	754	10	83½	38	77½	715
19 *or* 20	283 *or* 314	9	35	315	33	855	10	89½	41	82½	875
21	346	9	40	360	36	1017	10	93½	46	85½	930
22	380	10	41	410	39	1194	10	97½	47	89	1000
23 *or* 24	415 *or* 452	10½	43	451	41	1320	11	101½	49	93	1095
25	491	11	45	495	44	1520	11	105½	51	97	1455
26	531	11	48	528	46	1662	12	109½	54	99½	1600
27	572	11	51	561	49	1885	12	113½	57	103½	1700
28	621	11½	54	621	52	2123	12	117½	60	109½	1855
29	660	12	57	684	55	2375	12	121½	63	111½	2035
30	707	12	60	720	58	2642	12	125½	66	115½	2155
31 *or* 32	754 *or* 804	12½	63	807	61	2922	13	129½	69	118½	2250
33	855	13	66	858	64	3217	13	133½	72	122½	2420
34	908	13½	69	932	67	3525	13	137½	75	126½	2555
35	962	14	72	1008	70	3848	14	141½	78	129½	2745
36 *or* 37	1017 *or* 1075	14½	75	1087	73	4185	14	145½	81	133½	2900
38	1134	15	78	1170	76	4536	14	149½	84	137½	3065
39 *or* 40	1194 *or* 1256	15½	81	1255	79	4901	14	153½	87	141½	3235
41	1320	16	84	1344	82	5281	14	157½	90	145½	3395

In one collector which is primarily a cyclone an electrical precipitator is incorporated to obtain better collecting efficiency (see figure 59). The construction is unique in that only about 15% of the air handled by the cyclone passes through the precipitator. As

shown in the figure, it is the air near the wall of the larger-diameter cyclone tubes which enters the precipitator. The purpose of this arrangement is to collect in the electrical precipitator that fine dust which is thrown to the outside in the cyclone but which is too small in size to settle in a turbulent air stream. The central air

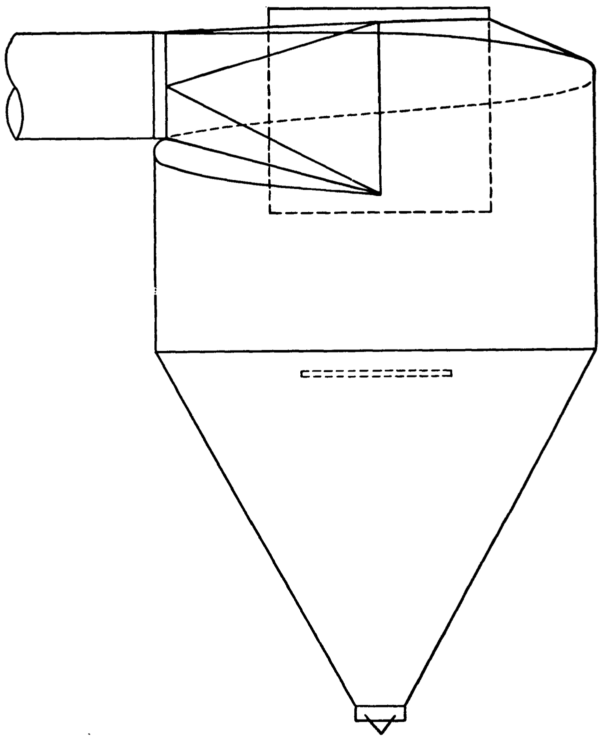


FIGURE 57. Helical Top Cyclone (*Courtesy "Design of Industrial Exhaust Systems"*)

stream which does not pass through the precipitation contains considerably less dust than that near the periphery.

The *dynamic precipitator* as shown in figure 60 is actually a specially designed exhauster which serves the dual purpose of moving the air and removing the dust. The unique design of the impeller coupled with that of the scroll makes of this exhauster a combination unit.

A similar unit in which the dynamic precipitating action is supplemented by a water spray or washing effect is shown in figure 61.

Thus, in this dual unit (exhauster collector) are combined two air cleaning principles—dynamic precipitation and washing. Dynamic precipitators are particularly well adapted for dust-control installations where equipment space is at a premium, and an unusually high dust-removal efficiency is not necessary.

Filters, usually cloth or paper, are particularly well adapted for installations where high efficiencies are necessary for reclamation of

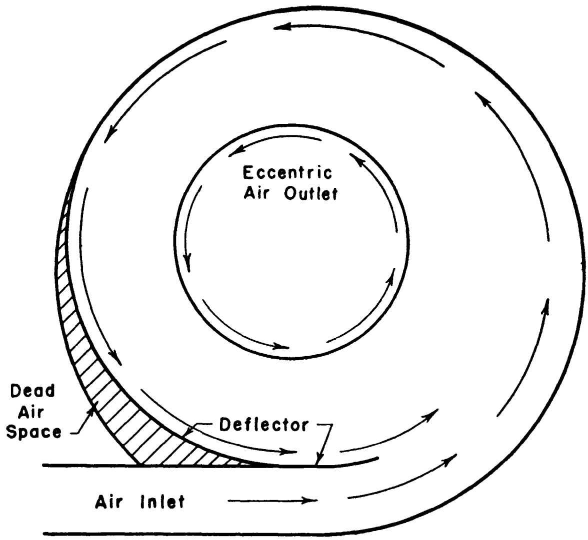


FIGURE 58. Cyclone with Inlet Deflectors (*Courtesy "Design of Industrial Exhaust Systems"*)

valuable material, where recirculation is desired as a means of reducing heat losses, or in residential areas where it is illegal to discharge considerable material into the air. The first cost of such collectors is quite high, but maintenance is simple if the collectors are taken care of properly, and their life is extremely long. Precleaning is usually necessary to avoid frequent rapping, overloading, and tearing of the filter material. Filters either of the screen or tube type, if well engineered and maintained, are capable of removing 99% or more of particles as small as 0.5 micron. In spite of this high efficiency, however, the effluent air may contain harmful quantities of toxic materials if the entering air is heavily loaded with fines.

A popular filter fabric for commercial dust collectors in this coun-

try is heavy cotton fabric, about 10 oz per square yard. Filter cloths of this type have considerable strength in order to support the collected dust and withstand the cleaning (rapping) operations. Also, they are sufficiently wear resistant to withstand the abrasive

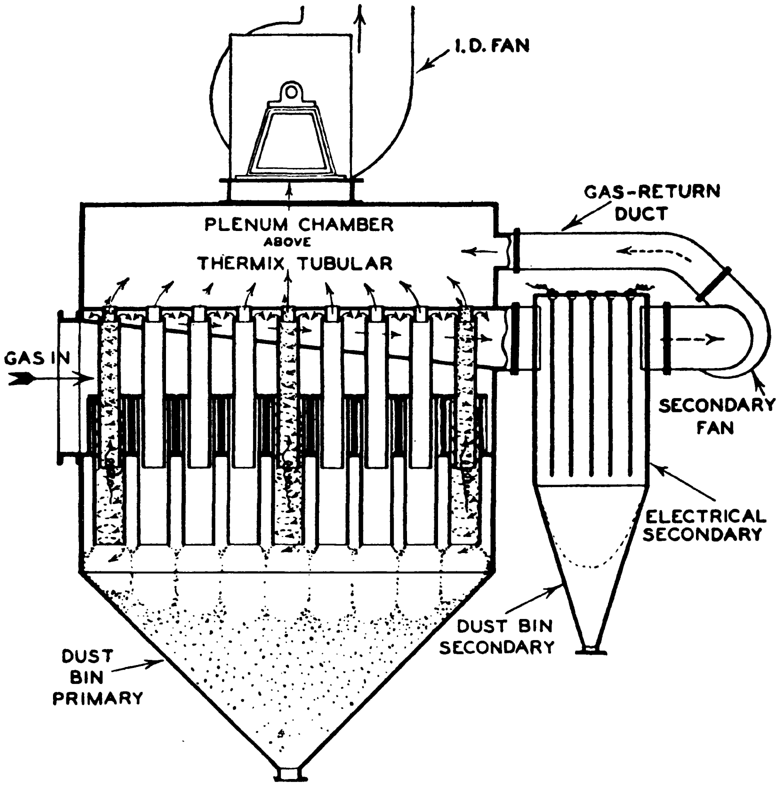


FIGURE 59. Combination Cyclone and Electrostatic Precipitator (*Courtesy Prat-Daniel Corp.*)

action of the dusts. The filtering efficiency of fabrics of this nature is lowest when new, as low as 80% or less by weight against a standard test dust as used by the Bureau of Mines for respirator testing.[3] However, the collected dust forms its own filter on the upstream face of the fabric after it has been in operation for a short while. Thereafter the collecting efficiency is lowest after each cleaning operation and at a peak just prior to such operation, but it never sinks to the low level of the new filter fabric.

The optimum air velocity through the filter medium depends upon several factors, including (1) the dust loading of the entering air, (2) the plugging characteristics of the particulate matter, (3) the maximum allowable pressure drop, and (4) the frequency of cleaning. The filtering velocity in practice varies from about 1.0 to 6.0 fpm (1.0 to 6.0 cfm per square foot of filter medium area) with a

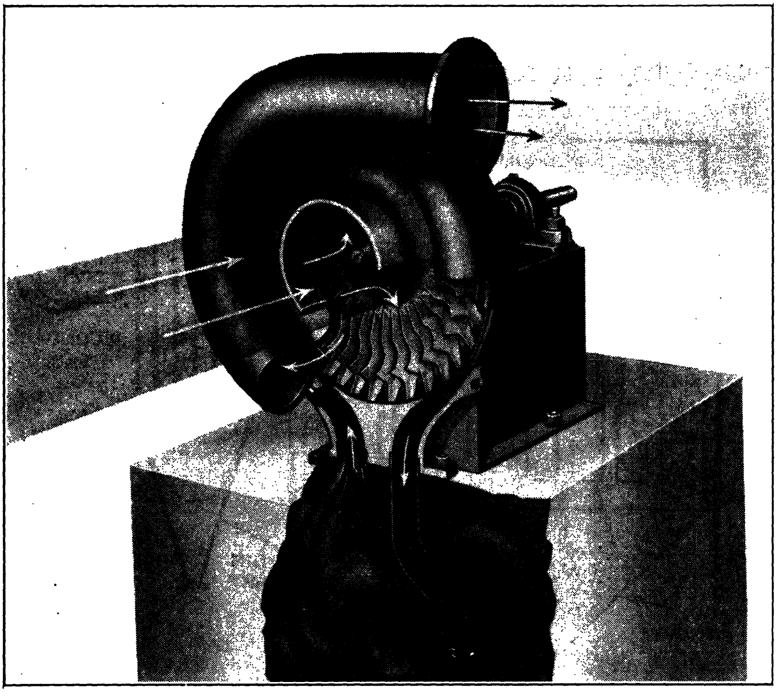


FIGURE 60. Dynamic Precipitator (*Courtesy American Air Filter Co.*)

most common value of about 3.0 fpm. Velocities as high as 9 fpm with successful filter operation have been reported.[30]

The filter is inherently a high-resistance cleaner, the pressure drop being commonly in the range of 2 to 5 in. of water. Experience has led to the general acceptance of 3 in. of water as the maximum allowable resistance for collectors of this type for good operation. The flow of air through the filter medium is, therefore, laminar or streamline in nature, and the pressure drop across it is proportional to the velocity.

The filter area is usually selected on the basis of the volume of

air to be handled and the maximum filter velocity. This may result in undersize filters, or units which are needlessly large and costly.[85, 86] For example, two cloth-filter installations are reported to have had resistances of 5.0 and 0.5 in. of water after 4 hours and 6 days,

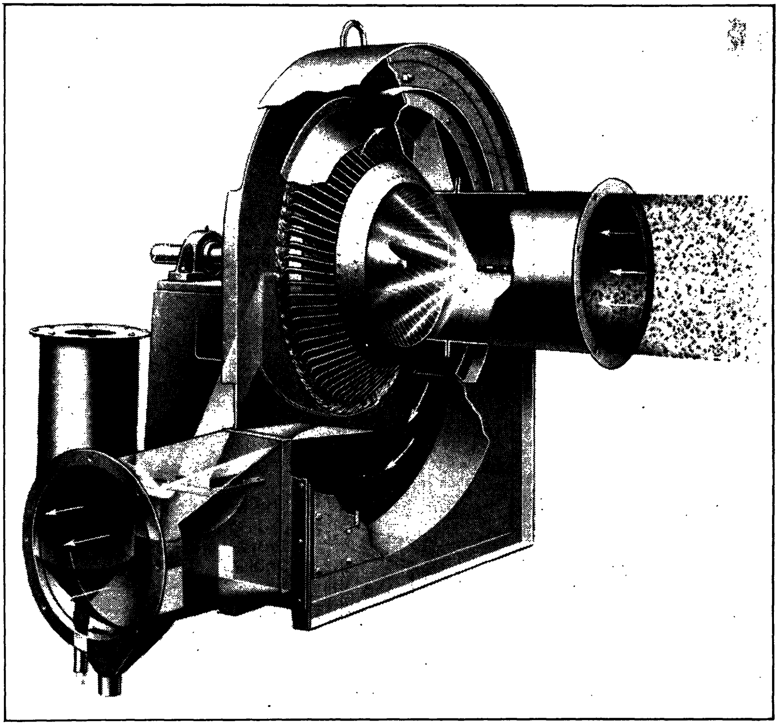


FIGURE 61. Combination Dynamic Precipitator and Wet Collector (*Courtesy American Air Filter Co.*)

respectively, of operation. The filter velocity was about 2 fpm in the first case and 3 fpm in the second, and the dust loading was about the same in both cases. The difference was in the particle size, the higher filter resistance having been associated with the finer material. It is evident, therefore, that for satisfactory operation of filter collectors the particle size must be taken into consideration. Industrial hygiene engineers would do well to study carefully references 85 and 86 before making specific size recommendations for filter-type collectors.

Typical filter collectors are shown in figures 62, 63, 64, 65, and 66. Figure 62 illustrates the filter-type collector in its simplest form. Figures 63 and 64 show commercial units of the filter-screen type, figure 65 shows a commercial collector of the filter-tube type, and figure 66 the cloth-bag (cloth-screen) type.

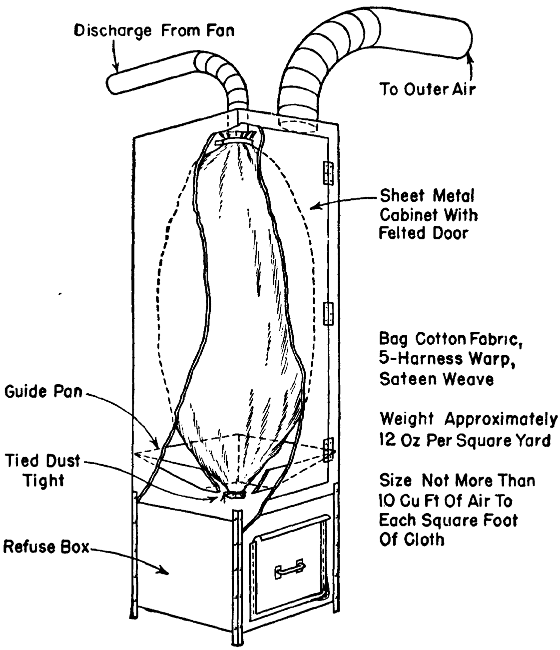


FIGURE 62. Simple Cloth Filter Collector (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

Wet collectors of commercial design for dust collection are of fairly recent origin. Air washers and other spray devices for air cleaning and even for dust control are not new, but their commercial counterpart for local exhaust systems first became available about two decades ago.

Like all collectors, these have their advantages and disadvantages. In general (1) their first cost is fairly high, (2) their filtering efficiency is lower than filter collectors, (3) their pressure loss is as high as or higher than filter collectors, (4) their maintenance and operating cost is low, (5) their space requirements are less than filter collectors, (6) they are particularly well adapted for flammable or

explosive dusts, and (7) they are satisfactory for high dust loadings.

As indicated previously, the collecting efficiency of wet collectors is not as high as filter collectors in general. Kravath,[87] however, mentions a commercial wet collector which he states is practically as efficient as the cloth filter as a cleaning unit. It has been the author's experience recently that such collectors are highly efficient

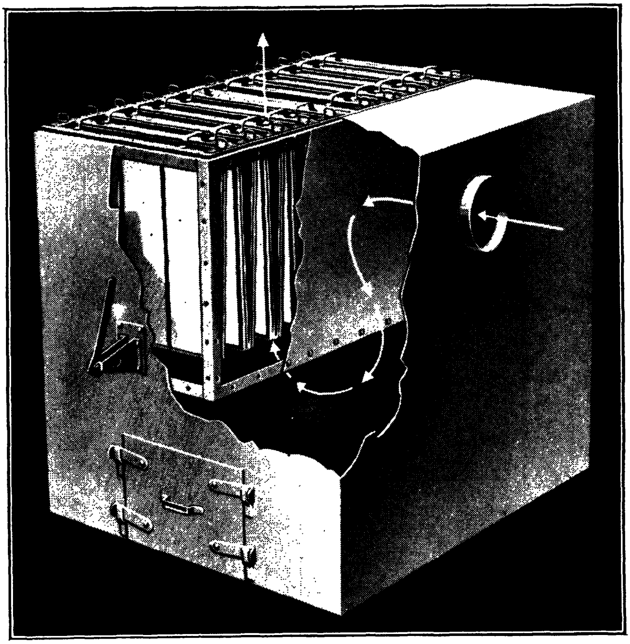


FIGURE 63. Filter Screen Collector (*Courtesy American Air Filter Co.*)

against the larger particle size groups but relatively inefficient against fumes the particle size of which was probably in the order of 0.5 micron. In a dust control installation at a gyratory screening operation involving bulk material, the amount of dust escaping through the collector was less than 0.3 mg/m^3 even though the concentration of material in the entering air was in the order of 100 mg/m^3 (filtering efficiency over 99%). On the other hand, with a loading of fume from a melting pot in the order of 20 to 60 mg/m^3, the collecting efficiency was only 50 to 60%. This is not a criticism of these collectors; the removal of fumes by any method except electrical precipitation is extremely difficult. Furthermore, against dust of a

larger size range the efficiency of the collector was as high as necessary.

Wet collectors operate usually on a combination of filtering principles. These include centrifugal action, inertial action, and wet-

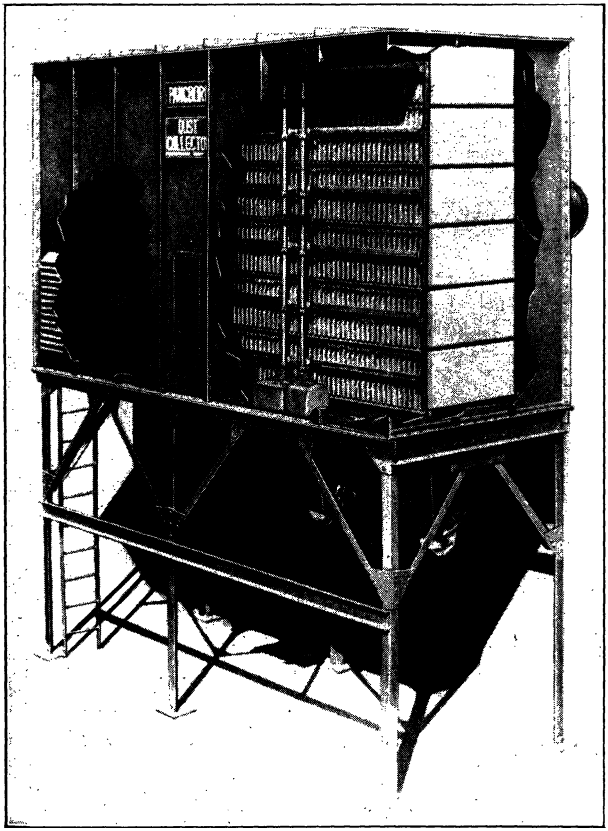


FIGURE 64. Filter Screen Collector (*Courtesy the Pangborn Corp.*)

ting of the particles by means of water curtains, sprays, or mists. The wetting action is sometimes enhanced by the use of wetting agents in the collecting liquid. Some of these principles as applied to scrubbers for flue gases are described in reference 88. The collecting principles of a few commercial units are indicated in figures 67, 68, and 69.

The resistance of the different makes varies considerably although it is usually in the order of 2.5 to 4 in. of water. When designing

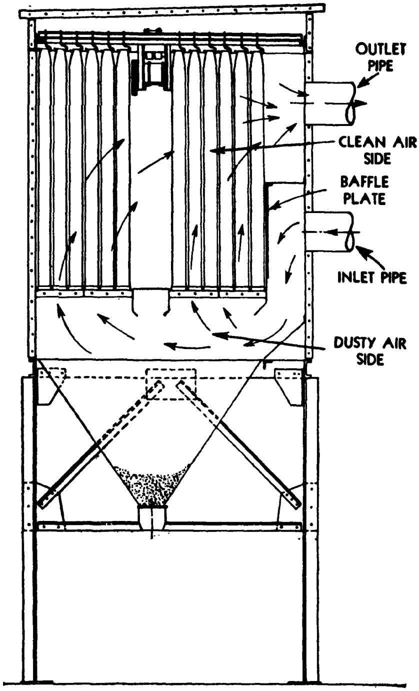


FIGURE 65. Cloth Tube Collector (*Courtesy American Foundry Equipment Co.*)

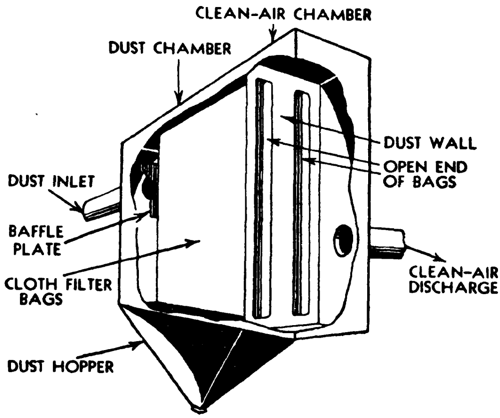


FIGURE 66. Bag-Type Filter Collector (*Courtesy W. W. Sly Manufacturing Co.*)

systems which are to include wet collectors, it is advisable to obtain data on the pressure loss through the collector from the manufacturer.

Electrostatic precipitators present probably the most efficient collecting units. The first cost is very high, and the maintenance cost

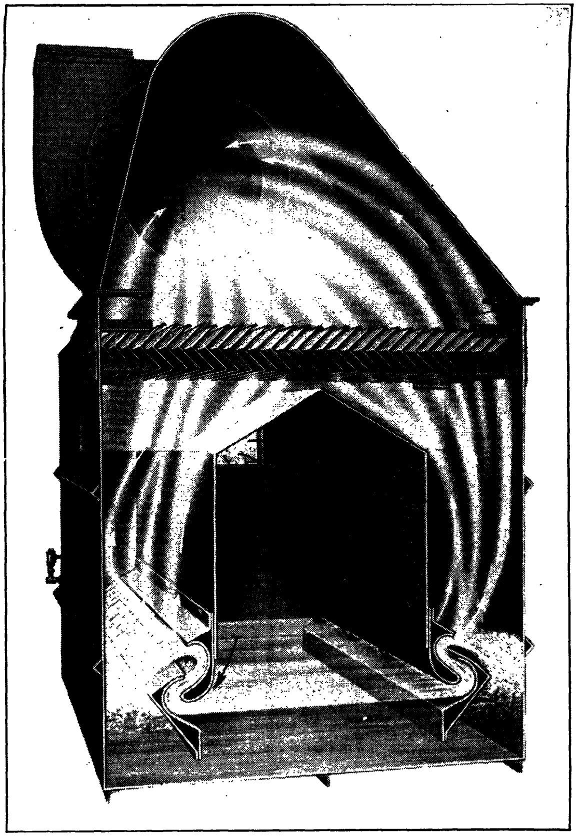


FIGURE 67. Wet Collector (*Courtesy American Air Filter Co.*)

is high enough to discourage their use in local exhaust or industrial exhaust ventilating systems at present, except where extremely valuable materials are recovered, or the air is recirculated. Their use is not common at present but will probably become more so as the installation and maintenance costs decrease and as emphasis on reducing heat loss increases.

Precipitators in general require precleaners if the dust loading is

heavy to avoid the necessity for frequent cleaning. The resistance through them is lower than any other type of collector.

In effect, this type of collector consists of a chamber in which are located a number of positively charged electrodes, each of which is

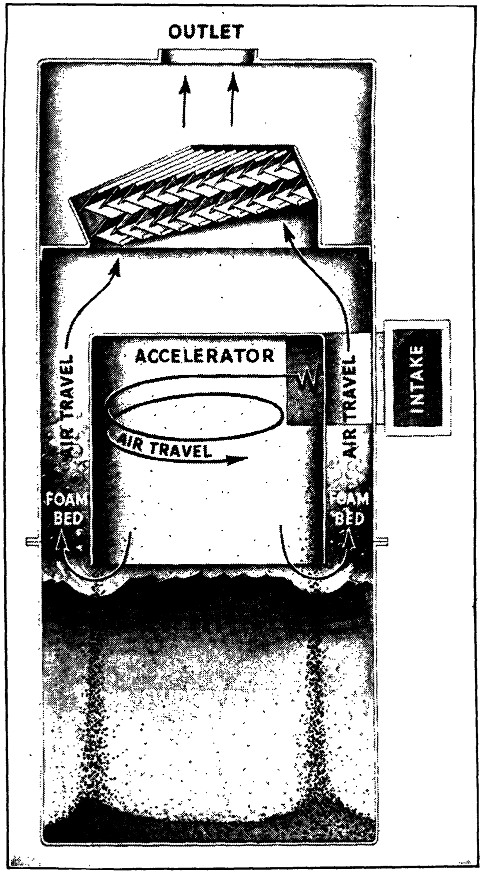


FIGURE 68. Wet Collector (*Courtesy R. C. Mahon Co.*)

centrally located with respect to electrically grounded pipes or plates and which is insulated from them. The contaminated air passes through the chamber and, under the influence of a strong electrostatic field, the entrained matter is ionized and collected. In a recent electrostatic precipitator, the collector consists of two units, the ionizing unit and the collecting unit, which are located in the

order named as regards air flow. Hence, the particulate matter is first ionized before entering the collector proper. The purpose of this arrangement is to obtain more efficient collection with a less

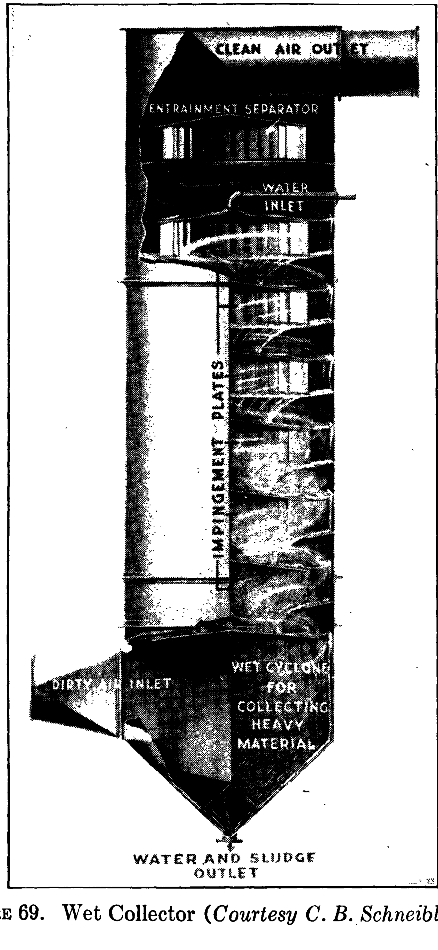


FIGURE 69. Wet Collector (*Courtesy C. B. Schneible Co.*)

intense electrostatic field in the collector. To obtain voltage of the proper type and magnitude for charging the electrodes, considerable transforming and rectifying equipment is necessary. This equipment is costly and keeps the cost of the collector out of reach for most jobs.

One type of electrostatic precipitator which is enjoying consider-

able demand is that designed specifically for mists such as are encountered in large production machine shops. Even though these mists do not usually constitute a health hazard, they are a nuisance of the first order and are also a safety hazard. Since these mists are difficult of collection by any other means, the cost of the electrostatic precipitator can often be justified for installations of this nature.

CHAPTER VIII

EXHAUSTERS

For the purposes of industrial hygiene engineering, exhausters may be classified conveniently into four major groups:

1. Gravity stacks.
2. Automatic ventilators.
3. Fans.
4. Ejectors.

The first two groups, while very common and of considerable importance in atmospheric sanitation, are of relatively little interest to industrial hygiene engineers. Their value and usefulness must, however, not be underrated. In many industries, health hazards do not exist simply because of the preventive protection afforded by gravity stacks, automatic ventilators, and natural ventilation produced by other conditions. Their common use in industry generally automatically precludes their usefulness to industrial health engineers since, as a rule, if the solution were one of a gravity stack or automatic ventilator it would probably already have been taken care of. Fans provide the most important source of air-moving equipment both for general ventilation and especially for local exhaust systems. The low operating efficiency of ejectors hampers their more common use. There is, however, an important niche in the exhauster field which is filled better by devices of this kind than by any other.

GRAVITY STACKS

Very little space will be devoted to the discussion of these devices since their use by industrial hygiene engineers is very infrequent. Gravity stacks or chimneys are particularly satisfactory for the control of obnoxious and nuisance contaminants from heated operations which can be partially or wholly enclosed. If the temperature difference is operative continuously, and if the operation can be almost completely enclosed, gravity stacks provide adequate control

for even toxic materials. They should not be recommended, however, unless there is a substantial temperature difference. Proper consideration must be given also to the height of the stack and place of discharge. For example, the author encountered one installation where the stack ended about 6 ft above the roof but below the peak and in the corner of an L-shaped roof. In addition, the stack happened to be on the windward side (as regards the prevailing wind) of the two gables on a building located in open flat country. The pressure created by the wind in the roof corner where the stack was located was sufficient to overcome the thermal head in the stack, and air was being blown to the operation a good part of the time rather than exhausted from it.

The pressure difference or static head which is produced in gravity stacks may be computed as follows:

$$D_t = 2.96HB\left(\frac{W_R}{T_R} - \frac{W_S}{T_S}\right) \tag{22}$$

where D_t = pressure difference in inches of water.
H = height of stack in feet.
B = barometric pressure in inches of mercury.
W_R = density in pounds per cubic foot of room air at 0° F and 1 atmosphere pressure.
W_S = density in pounds per cubic foot of air in stack at 0° F and 1 atmosphere pressure.
T_R = absolute temperature of room air in ° F.
T_S = absolute temperature of stack air in ° F.

Since both W_R and W_S are about 0.075 in most instances and since B is about 29.92 except at considerable elevation, equation 22 may be rewritten as follows, for all practical purposes:

$$D_t = 6.65H\left(\frac{1}{T_R} - \frac{1}{T_S}\right) \tag{23}$$

Except in rare instances, D_t is very small, and it is necessary to use relatively large diameter stacks to handle substantial quantities of air since the velocity will be low.

AUTOMATIC VENTILATORS

This group of exhausters consists of those devices which are intended to produce air flow by converting the energy of the wind

or outside air movement into suction. Like gravity stacks, they cannot be depended upon and are, in fact, even more erratic than such stacks since no suction is produced unless there is significant outdoor air movement. Their interest to industrial hygiene engineers is not great for reasons given earlier. Nevertheless they do much good in industrial atmospheric sanitation by virtue of their very common use to remove contaminants and heat from operations which, while not severe health hazards, would otherwise require our consideration.

Automatic ventilators were classified by Calderwood and Mack[89] as follows:

1. Plain stationary.
2. Stationary siphoning.
3. Plain rotary.
4. Rotary siphoning.

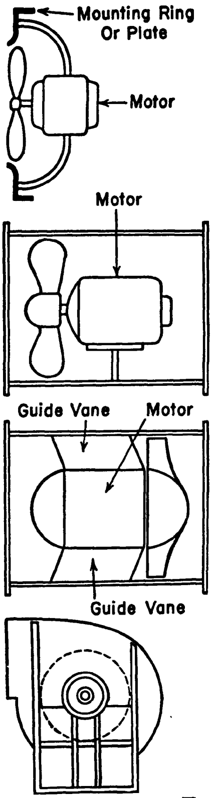
These investigators found the order of effectiveness of the different types of ventilators to be the reverse of the above listing; that is, the rotary siphons were best and the plain stationary ventilators worst. They conclude that the most effective action in inducing air through a ventilator is the vacuum produced in the wake of the wind. Since exhausters of this type are of relatively little importance to the industrial hygiene engineering profession, no more space will be devoted to a discussion of them.

FANS

Fans are by far the most important group of exhausters (also suppliers) for industrial atmospheric sanitation through ventilation —both general and local exhaust. They are usually classified as (1) axial flow or propellor type, and (2) radial flow or centrifugal type. However, the National Association of Fan Manufacturers has recently introduced a new classification in which propeller fans are subdivided into propeller, tubeaxial, and vaneaxial fans as shown in figure 70.

Axial-flow fans are made commercially in various designs and sizes. The form, number, thickness, length, and shape of the blades vary tremendously in different fans. Likewise, the quantity of air that such fans will move and the resistance against which they will operate varies a great deal. Many of the old-type propeller fans which are encountered in industry today move very little air if the

system resistance is high (above 1 or 2 in.). However, some of the newer axial-flow single-stage fans operate satisfactorily at 4 in. of water and above. Up to 4 in. these fans have a lower noise level than centrifugal fans; above 4 in. they operate in the same noise-level range as radial-flow fans.



PROPELLER FAN

A propeller fan consists of a propeller or disc-type wheel within a mounting ring or plate and including driving mechanism supports either for belt drive or direct connection.

TUBEAXIAL FAN

A tubeaxial fan consists of a propeller or disc-type wheel within a cylinder and including driving mechanism supports either for belt drive or direct connection.

VANEAXIAL FAN

A vaneaxial fan consists of a disc-type wheel within a cylinder, a set of air guide vanes located either before or after the wheel and including driving mechanism supports either for belt drive or direct connection.

CENTRIFUGAL FAN

A centrifugal fan consists of a fan rotor or wheel within a scroll type of housing and including driving mechanism supports either for belt drive or direct connection.

FIGURE 70. Fan Types (*Courtesy NAFM*)

Radial fans likewise are available commercially in many types and sizes. The two important elements in any centrifugal fan are the rotor or impeller and the casing, housing, scroll, or volute. The impeller blades are of three distinct types: (1) those curved forward in the direction of rotation (the squirrel-cage fans, not too satisfactory against the high resistances usually encountered in exhaust systems for air sanitation); (2) straight-blade or paddle-wheel types (the "old faithful" and very satisfactory for industrial

hygiene); and (3) those with the blades curved backward or counter to the direction of impeller rotation (the newer "constant-power" fans). These different fans are characterized as slow-speed, moderate-speed, and high-speed types, respectively, although the actual speed of operation of each type covers a wide and overlapping range. Very high-speed centrifugal fans may have the characteristics of low-pressure "compressors" if their speed of operation is such that they produce a 1-lb-per-square-inch pressure rise. As exhausters for industrial atmospheric sanitation, fans seldom produce more than a total of 10 to 15 in. of water, and as such are considerably below the range of compressors.

Fan Performance. All types of fans follow certain laws of performance which are useful in the selection of the proper fan, and in predicting the effect of changes in conditions upon their performance. According to the 1946 *ASHVE Guide*,[2] these laws are as follows, wherein Q = quantity; P = resistance, velocity, or total pressure; RPM = fan speed; and HP = power:

1. Variation in fan speed
   Constant air density—Constant system
   Q varies as RPM.
   P varies as RPM squared.
   HP varies as RPM cubed.
2. Variation in fan size
   Constant tip speed—Constant air density
   Constant fan proportions—Fixed point of rating
   Q varies as wheel diameter squared.
   P remains constant.
   RPM varies inversely as wheel diameter.
   HP varies as wheel diameter squared.
3. Variation in fan size
   Constant RPM—Constant air density
   Constant fan proportions—Fixed point of rating
   Q varies as wheel diameter cubed.
   P varies as wheel diameter squared.
   Tip speed varies as wheel diameter squared.
   HP varies as fifth power of wheel diameter.
4. Variation in air density
   Constant volume—Constant system
   Fixed fan size—Constant speed
   Q remains constant.
   P varies as density.
   HP varies as density.
5. Variation in air density.
   Constant pressure—Constant system
   Fixed fan size—Variable speed

Q varies inversely as square root of density.
P remains constant.
RPM varies inversely as square root of density.
HP varies inversely as square root of density.

6. Variation in air density
   Constant weight of air—Constant system
   Fixed fan size—Variable speed
   Q varies inversely as density.
   P varies inversely as density.
   RPM varies inversely as density.
   HP varies inversely as density squared.

In addition to the foregoing fan laws the "laws of homologous fans" which apply to different sizes of similar fans are very useful. These laws are:

Q varies as the ratio of size cubed, times the ratio of RPM.
P varies as the ratio of size squared, times the ratio of RPM squared.
HP varies as the ratio of the size to the fifth power, times the ratio of RPM cubed.

Fan Efficiency. The efficiency of a fan is the ratio of the horsepower output to the horsepower input. The horsepower output of a fan is given by [90]

$$HP = \frac{Q \times TP}{6356} \tag{24}$$

where Q = air flow in cubic feet per minute.
TP = total pressure in inches of water.

If the resistance pressure is used in the foregoing equation in place of the total pressure, it is assumed that it (resistance pressure) represents the useful pressure, the true resistance to air flow, and that the velocity pressure is lost in the duct system and as the air leaves the system from the discharge stack. In the standards for published capacity tables as adopted by the National Association of Fan Manufacturers, the term "static pressure" (resistance pressure)refers to the true resistance to air flow. Such tables charge both the fan inlet and outlet velocity to fan performance and may be used directly where the resistance pressure of the system as calculated represents the true resistance pressure. In this connection it will be remembered that one VP was subtracted from the TP in the sample calculations in Chapter VI to determine the fan pressure.

The fan static efficiency is then given by the following equation:

$$E_S = \frac{Q \times RP}{6356 \times HP} \tag{25}$$

where E_s = static efficiency.
Q = air flow in cubic feet per minute.
RP = true resistance pressure.
HP = horsepower input.

This value is not the best index of a fan's true efficiency since different fans may move the same quantity of air against the same resistance pressure and with the same power input but with significantly different fan outlet velocities. The mechanical or true efficiency of the fan with a high outlet velocity will, of course, be greater under the foregoing conditions than that of the fan with a low outlet velocity. Hence, the mechanical efficiency of a fan is best expressed as follows:

$$E_m = \frac{Q \times TP}{6356 \times HP} \tag{26}$$

where E_m is equal to mechanical efficiency and Q, TP, and HP are as given in equations 24 and 25.

Performance Characteristics. The efficiency of a fan operating at a fixed speed will vary with the RP against which it operates. The peak efficiency for different fans varies with the ratio of Q to that which would obtain if the fan were running free. Variations in efficiency accompany variations in pressures and power consumption which are characteristic of the individual designs and which are influenced particularly by the shape and design of the impeller blades. Variations of this kind in pressure, power, and efficiency are shown by characteristic curves which are very useful in fan selection. Examples of characteristic curves are shown in figures 71, 72, and 73.

One of the most important considerations in the selection of a fan is power consumption. Consequently, it is desirable to select one with a high operating efficiency at the pressure and volume under which it will actually operate. It must be borne in mind, however, that in many systems the volume does not remain constant, and in any system the actual resistance may vary substantially from the computed value. It is therefore advisable to select a fan which has

a high flat efficiency curve over a fairly wide range in the vicinity of the estimated pressure and volume, in preference to one which has a higher peak efficiency at the estimated values but which drops

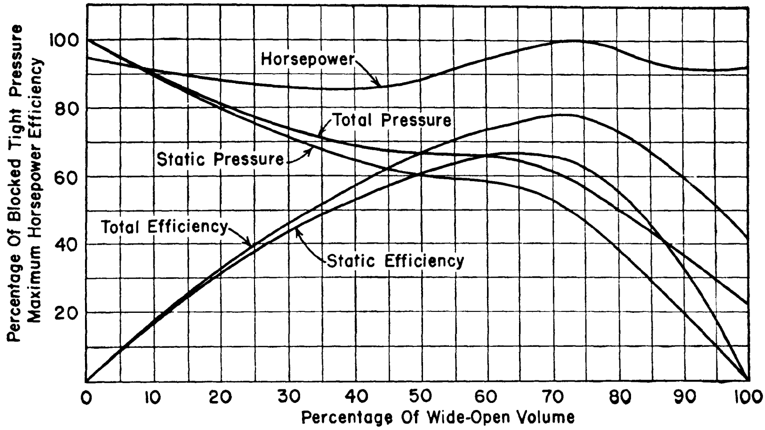


FIGURE 71. Operating Characteristics of Axial-Flow Airfoil-Type Fan (*Courtesy Heating, Ventilating and Air Conditioning Guide*)

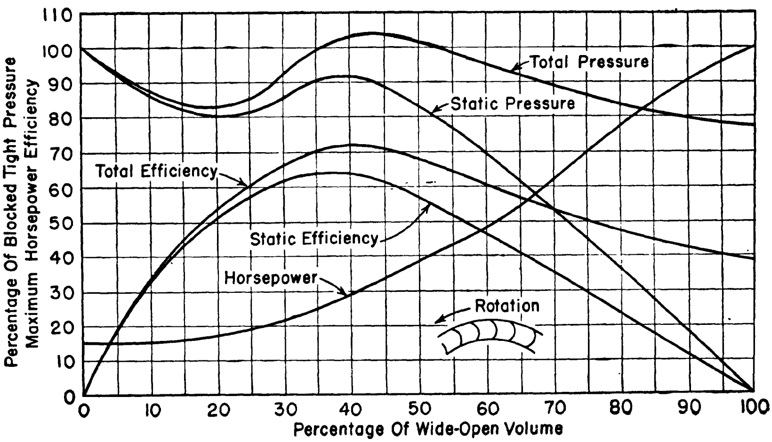


FIGURE 72. Operating Characteristics of Forwardly Curved Blade Fan (*Courtesy Heating, Ventilating and Air Conditioning Guide*)

sharply in both directions. If first cost is a more important consideration than added horsepower, upkeep, and noise, smaller fans with higher speeds may be used. Such fans usually operate to the right of the efficiency peak. Fans are ordinarily not selected to

the left of the peak of the static efficiency curve as such units are larger, cost more, require more power, and sometimes produce more noise than those near or at the peak.

The curves in figures 71, 72, and 73 show the operating characteristics for three different types of fans: axial-flow airfoil fan, centrifugal fan with forwardly curved blades, and centrifugal fan with backwardly curved blades. These curves are intended only to

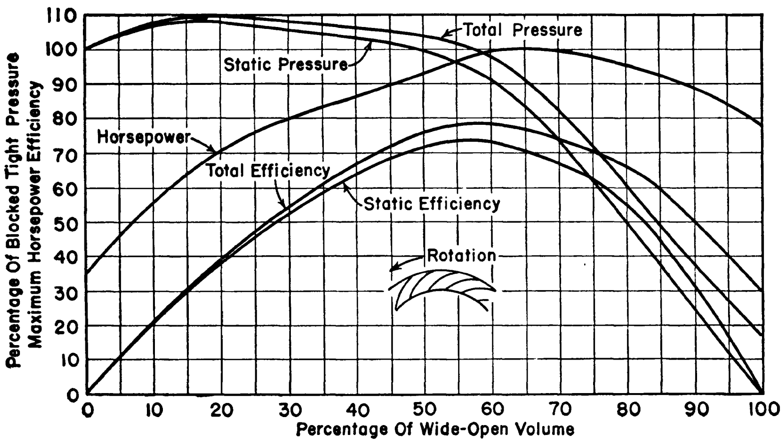


FIGURE 73. Operating Characteristics of Backwardly Curved Blade Fan (*Courtesy Heating, Ventilating and Air Conditioning Guide*)

show the variations in operating characteristics and not to serve in the actual selection of fans.

Fan Selection. Certain specific information is needed to permit the selection of the proper type, and the proper fan. This information is

1. Quantity of air to be moved.
2. Resistance pressure of system in which fan is to be installed.
3. Nature of load; variations in 1 and 2 above.
4. Space limitations.
5. Type of motive power available.
6. Amount of noise permissible.

Other considerations involved in fan selection are (1) efficiency, (2) first cost versus upkeep and power consumption, and (3) fan speed.

It is apparent from the foregoing discussion of the characteris-

tics of fans that the selection of the best fan for a given job is not simple. To facilitate the choice of a suitable unit, the various fan manufacturers supply tables or curves of their products showing the following factors for each size of fan.

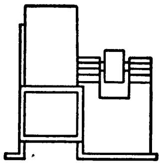
1. Quantity of air handled.
2. Resistance pressure.
3. Outlet velocity.
4. Speed.
5. Brake horsepower.
6. Tip or peripheral speed.
7. Dimensions.

In addition, the most efficient operating point is frequently indicated by bold face type or italics.

It must be emphasized that, for any given fan, the quantity of air handled at a specific static pressure is handled only at that pressure and at no other, other things being equal. At higher pressures, less air will be handled and more air at lower pressures. It is important, therefore, that the resistance pressure be computed as accurately as possible and that provision be made in the calculations for future expansion. If the actual resistance pressure is considerably above the estimated value, Q will suffer, and the control will probably be inadequate; and if additional branches are added to an unprepared system, Q in each branch will drop proportionately, with unsatisfactory results.

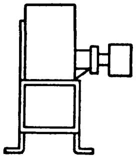
The type of drive, direction of rotation, and direction of fan outlet are dictated by the circumstances and conditions existing at the location where the fan is to be placed. To avoid the misunderstanding, delivery delays, and unnecessary expenses resulting from erroneous designation of centrifugal fans, the National Association of Fan Manufacturers and the American Society of Heating and Ventilating Engineers have standardized fan designations and terminology. Standard designation of fan-drive arrangements are shown in figure 74. Other recommended standard designations are as follows:

1. *Direction of Rotation.* Facing the driving side of the fan, blower, or blast wheel, if the proper direction of rotation is *clockwise,* the fan is designated as clockwise; if counterclockwise, the designation is *counterclockwise.* (The driving side of a single-inlet fan is the side opposite the inlet, regardless of the actual location of the drive.)



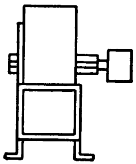
ARRANGEMENT NO. 1

For belt drive. Wheel overhung. Bearings on pedestal.



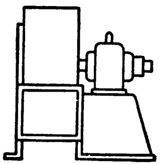
ARRANGEMENT NO. 2

For belt drive. Pulley and wheel overhung. Bearings in bracket on fan housing. Made only in smaller sizes for reversible discharge.



ARRANGEMENT NO. 3

For belt drive. Pulley overhung. Bearings supported on fan housing.

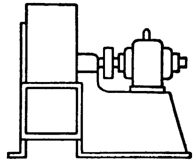


ARRANGEMENT NO. 4

For direct drive. Wheel overhung. No bearings on fan. Wheel mounted on motor or engine shaft. Pedestal for motor or engine.

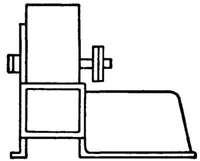
ARRANGEMENT NO. 5

For direct drive. Wheel overhung. Includes housing, wheel, shaft, one intermediate bearing, flanged coupling, and pedestal only for motor or engine.



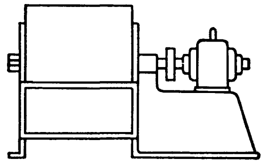
ARRANGEMENT NO. 6

For direct drive. Three-bearing arrangement with fan bearing at inlet side. Includes housing, wheel, shaft, one bearing (in inlet), rigid coupling, and pedestal only for motor or engine.



ARRANGEMENT NO. 7

For direct drive. Similar to Arrangement 6 but with two bearings on fan and flexible instead of rigid coupling.



ARRANGEMENT NO. 8

Similar to Arrangement 5 but with two bearings on pedestal with motor and flexible instead of rigid coupling.

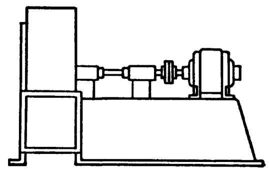


FIGURE 74. Fan-Drive Arrangements (*Courtesy NAFM*)

2. *Bottom Horizontal Discharge.* If the line of air discharge is horizontal and below the shaft.

3. *Top Horizontal Discharge.* If the line of discharge is horizontal and above the shaft.

4. *Up-Blast Discharge.* If the line of discharge is vertically upward.

5. *Down-Blast Discharge.* If the line of discharge is vertically downward.

6. *Intermediate Angular Discharges.* Either top or bottom angular up discharge or top or bottom angular down discharge, the smallest angle made by the line of air discharge with the horizontal being specified.

Fan Location and Maintenance. Wherever possible, particularly if abrasive or corrosive materials are being exhausted, the fan should be located downstream from the collector. Special materials or design of housing and impeller construction are useful in retarding rapid wear, corrosion, or abrasion, but where abrasive dust or corrosive gases are handled it is much better to locate the fan beyond the collector than to try to prevent wear or corrosion by special construction. Collectors for corrosive gases, however, are not particularly effective and are not in common use. Protective coatings for fan interiors and special materials for construction are, therefore, deserving of appropriate consideration when the contaminant to be exhausted is corrosive. For flammable or explosive contaminants, nonferrous impellers are essential. During the war, when industry was obliged to take what it could get, the safety hazard in fans handling explosive contaminants was reduced by providing a diverging-type fine water spray at the fan inlet. Such sprays had a threefold-explosion-prevention action: (1) the water passing through the fan kept the interior relatively clean, (2) the presence of the moisture prevented sparking, and (3) the water curtain at the fan inlet would tend to prevent a flame from propagating upstream through the duct if a spark or primary explosion should occur in the fan. This measure was successful with many contaminants but was found to be unsatisfactory with some contaminants, such as aluminum, which clung to the impeller blades and accumulated at different rates on the different blades thereby throwing the impeller out of balance and ruining the fans.

Fan maintenance is extremely important. It should be done on a scheduled, periodic basis, not hit or miss. The maintenance must

be the responsibility of a designated individual or department if it is to be done satisfactorily.

This discussion of fans is admittedly very sketchy. The subject is a large one, and books have been written on it alone. The brief summary in this book is intended only to give industrial hygiene engineers an introduction to the subject. For complete information on fans, standard references, such as 2 and 91, should be consulted as well as the publications of the National Association of Fan Manufacturers and the catalogs of the fan manufacturers.

EJECTORS

For certain types of installations, such as where the material being handled is extremely corrosive, flammable, explosive, hot, or sticky, it is desirable not to have the exhausted air pass through a fan. For this purpose the ejector (frequently called injector) offers a safe and practical solution. Ejectors, while comparatively very inefficient, can be made to operate satisfactorily with steam, water, compressed air, or air from blowers as the ejecting medium. Since steam, water, and even compressed air are needlessly wasteful of energy, the discussion in this section will be centered on ejectors operated by air from centrifugal blowers, although the same factors and considerations apply if one of the other media is used.

There are probably as many different designs of ejectors as there are people who have designed them. There is, however, very little difference in the operating characteristics of the different designs. Two basic shapes or designs are shown in figure 75, the shape on the left usually being designated the venturi ejector. A differently proportioned venturi ejector as recommended by the American Foundrymen's Association[92] is shown in figure 76, and another of different proportions is shown in figure 77. Possibly the most complete treatise on ejector design is given in reference 93. Other useful references are 80, 94, and 95.

Where ejectors are employed as exhausters, it is essential that the air velocity in the secondary system (the exhaust system) be kept as low as possible. Because of the inherently low efficiency of ejectors, the power consumption by the primary blower or source of energy is very high if the velocity and resistance pressures in the exhaust system are high. Even though an ejector can be made to serve as the air mover in an exhaust system having a total pressure

of 4 in. of water, it is advisable to keep the total pressure in the system down to 1 or 1½ in. of water. Where centrifugal fans serve as the primary source of power for ejectors, the jet or nozzle velocity is usually kept in the range of 8000 to 18,000 feet per minute.

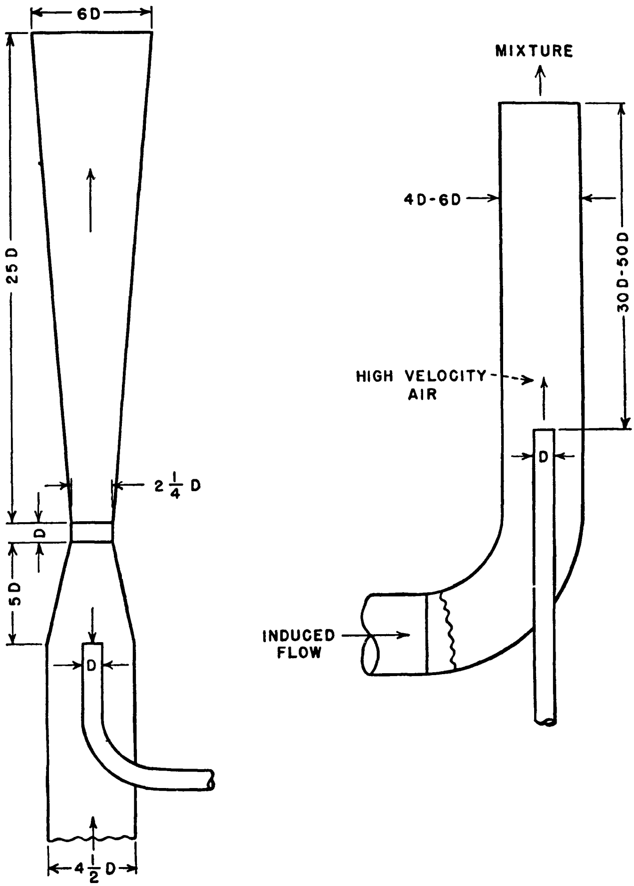


FIGURE 75. Ejectors (*Courtesy "Design of Industrial Exhaust Systems"*)

The calculations involved in the design of a venturi ejector and in the selection of a suitable fan as the primary air source are briefly as follows:

$$AHP_s = \frac{Q_s \times TP_s}{6356} \tag{27}$$

where AHP_s = air horsepower in the secondary or exhaust system.
Q_s = quantity of air in cubic feet per minute to be exhausted through the secondary system.
TP_s = total pressure in inches of water of the secondary system to the point where the ejector is installed.

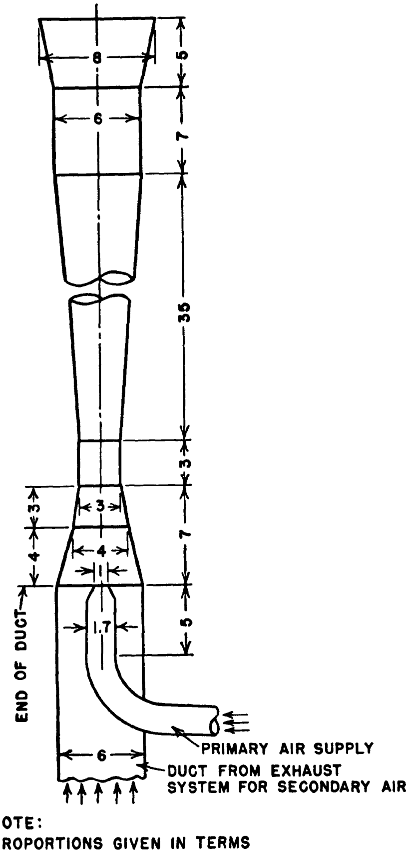
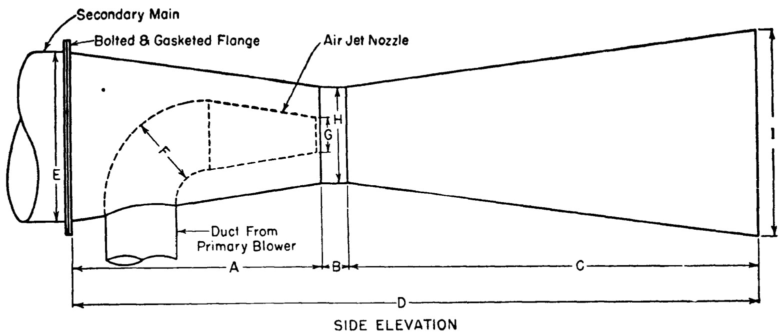


FIGURE 76. Venturi Ejector (*Courtesy AFA*)

$$AHP_p = 6.5AHP_s \tag{28}$$

where AHP_p = air horsepower of the primary air source.
AHP_s = same as in equation 27.

NOTE. The constant 6.5 varies somewhat with the ejector type and design and with TP_s. The value of 6.5 is a good average one.



Size No.	Length *				Diameter *				
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
1	15	2	25	42	10	4	2¼	6	13
2	18	2	30	50	12	5	2½	7	15
3	21	2	35	58	14	5	2¾	8	17
4	25	3	43	71	17	6	3½	10	22
5	31	3	53	87	21	8	4¼	13	26
6	37	4	63	107	25	9	4¾	15	31

* All dimensions are in inches.

FIGURE 77. Venturi Ejector with Dimension Details

$$V_p = 4920 \sqrt[3]{\frac{AHP_p}{A}} \tag{29}$$

where V_p = nozzle or jet air velocity in feet per minute.
AHP_p = air horsepower in primary system.
A = nozzle area in square feet.

$$Q_p = AV_p \tag{30}$$

where Q_p is equal to the quantity of primary air in cubic feet per minute and A and V_p are as in equation 29.

The *TP* of the primary system is computed the same as given in Chapter VI for other systems, the VP_p being that produced by the

velocity in the nozzle. With this information on the primary air supply a suitable fan can be selected.

Convenient dimensions and performance curves for six different sizes of venturi ejectors were prepared by one of the author's associates[96] during the war. These are shown in figures 77, 78, 79, 80, 81, 82, and 83. Instructions for the use of the curves are given in figure 78. Although the fan selection on these curves is based on the products of only one manufacturer, fans of other makes may be selected on the basis of comparable fans or from the data given in the first two steps of the instructions in figure 78.

As indicated previously, other types of ejectors, such, for example, as shown at the right of figure 75 also are in common use. Many of these are somewhat less efficient than venturi ejectors, but no serious errors will result, as a rule, if the same calculation procedures are followed. The same factors and considerations are involved also for compressed-air ejectors.

NO. 1 VENTURI EJECTOR NOZZLE - PERFORMANCE CURVES

EXAMPLE :-

Determine requirements of the Primary system to induce 500 CFM secondary air flow against 1" S P*

(1) From 500 CFM secondary volume, read vertically upward to intersection with 1" secondary resistance curve, from this point follow horizontally to the right and read 263 CFM primary air volume

(2) From the same point of intersection, follow horizontally to the left to intersection with primary SP curve, then vertically downward and read 11.08" SP primary resistance.

(3) Continue horizontally to the left from above mentioned point on primary SP curve to the intersections with the RPM and BHP curves and read vertically upward from each the respective values 4820 RPM and 0.73 BHP.

Note: If other than the indicated fan is used, its performance should conform to the primary CFM and SP requirements determined in (1) and (2) above

*Same as TP (See Fig. II in Appendix)

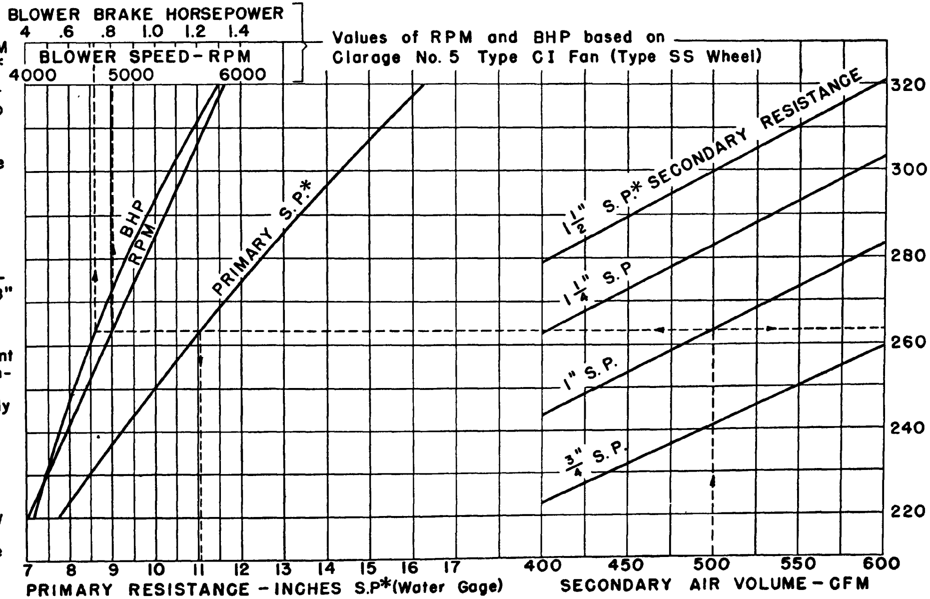


FIGURE 78. Curves for Ejector Calculations

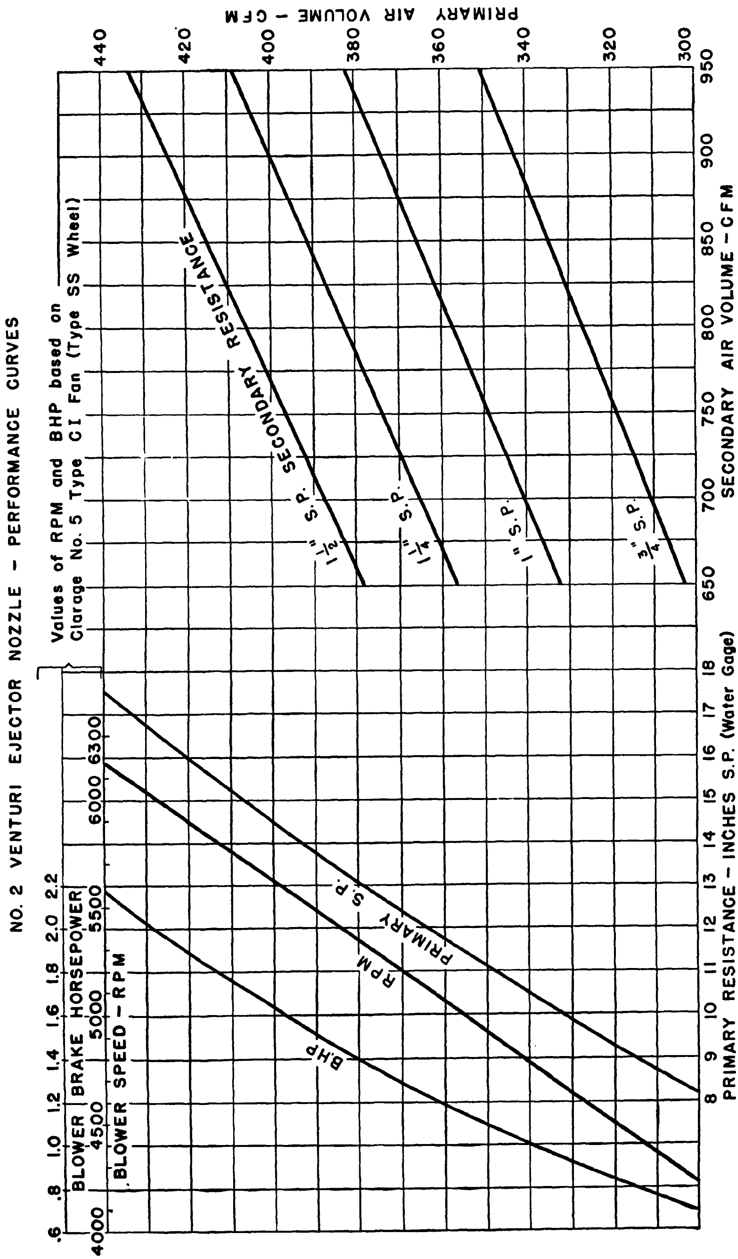


FIGURE 79. Curves for Ejector Calculations

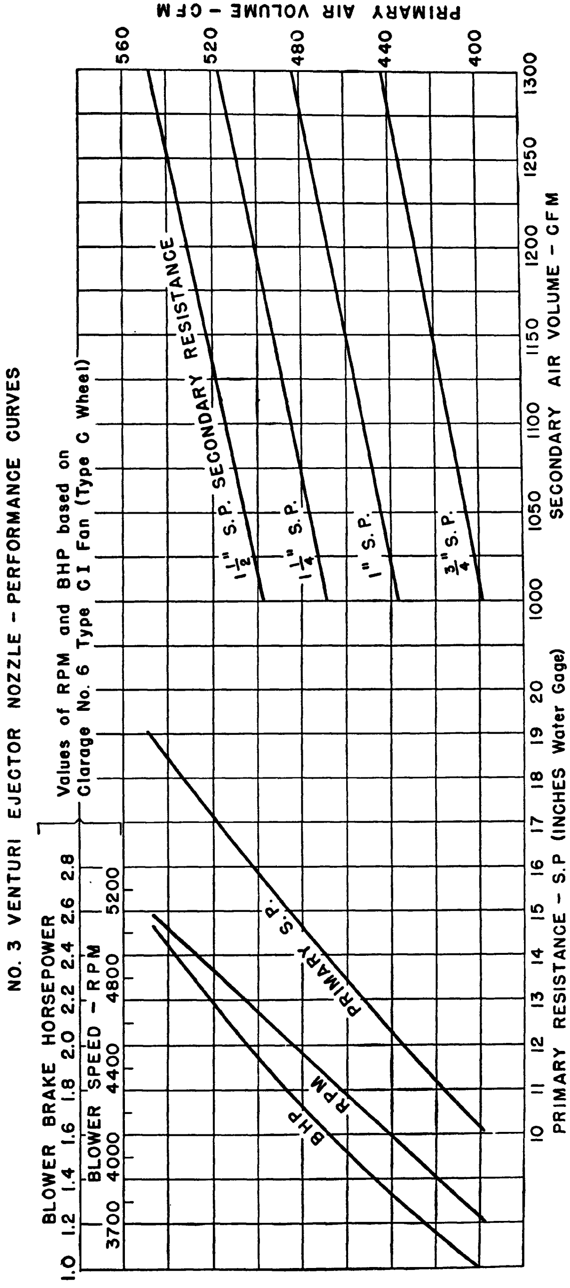


FIGURE 80. Curves for Ejector Calculations

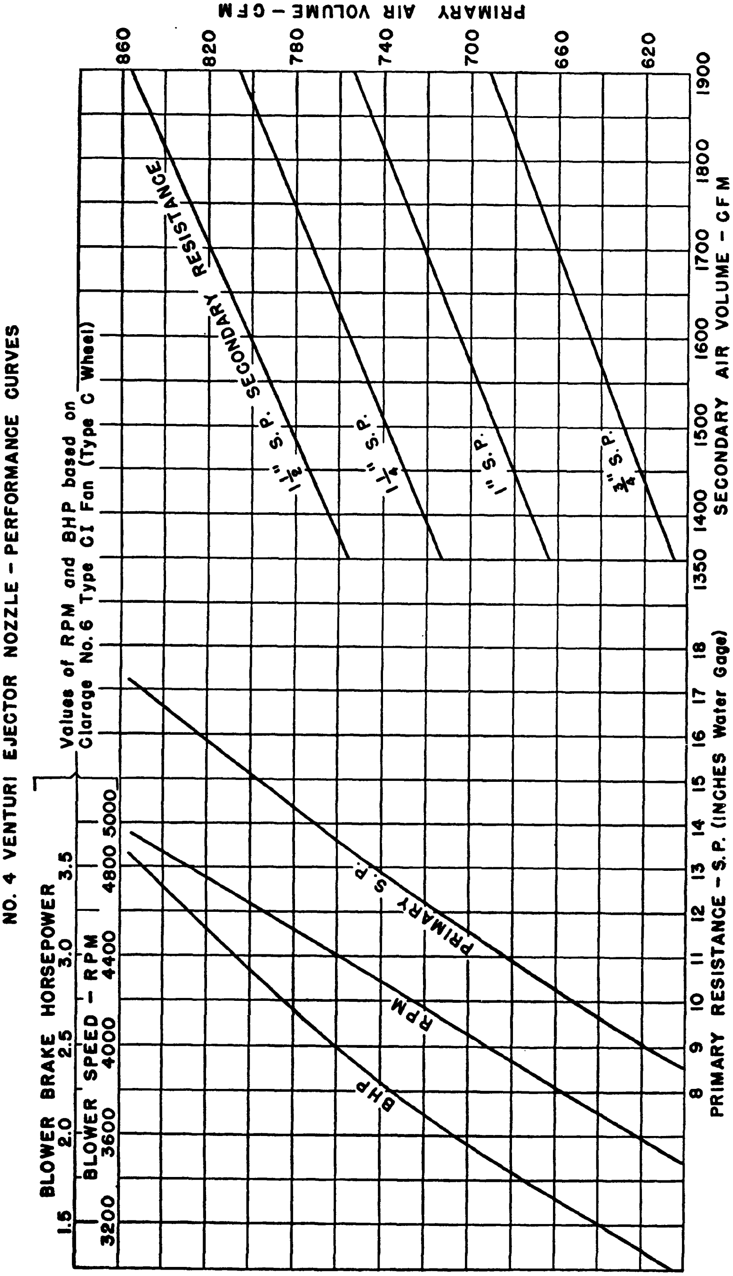


FIGURE 81. Curves for Ejector Calculations

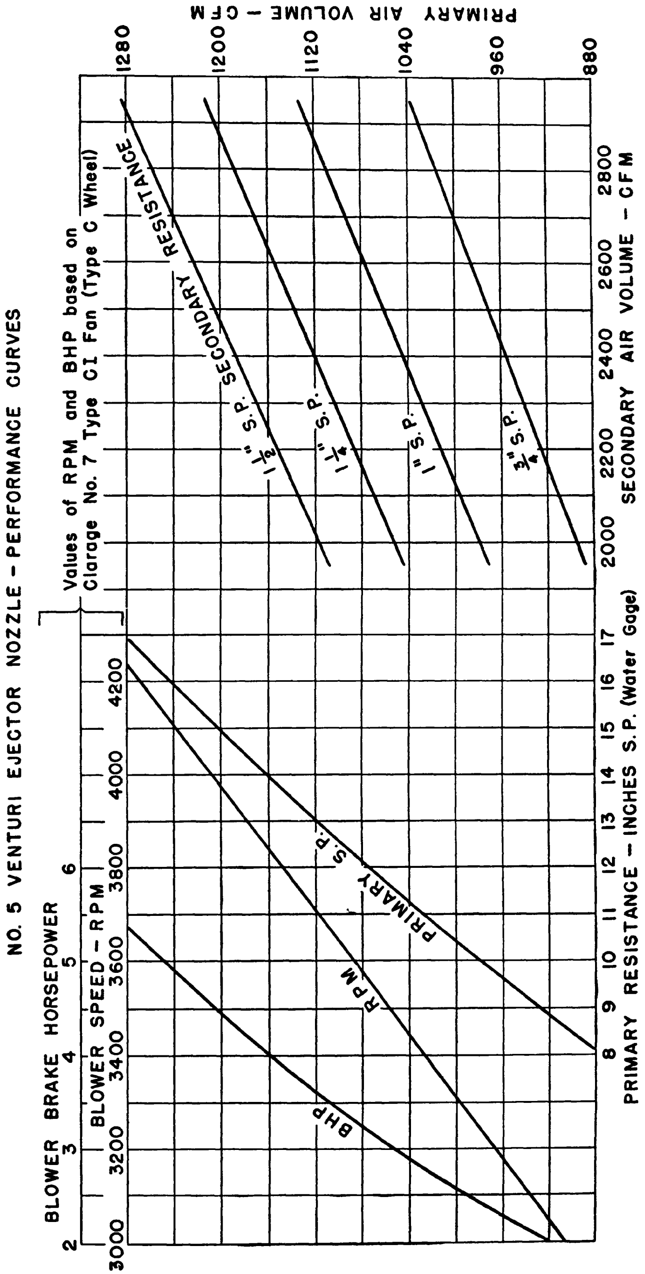


FIGURE 82. Curves for Ejector Calculations

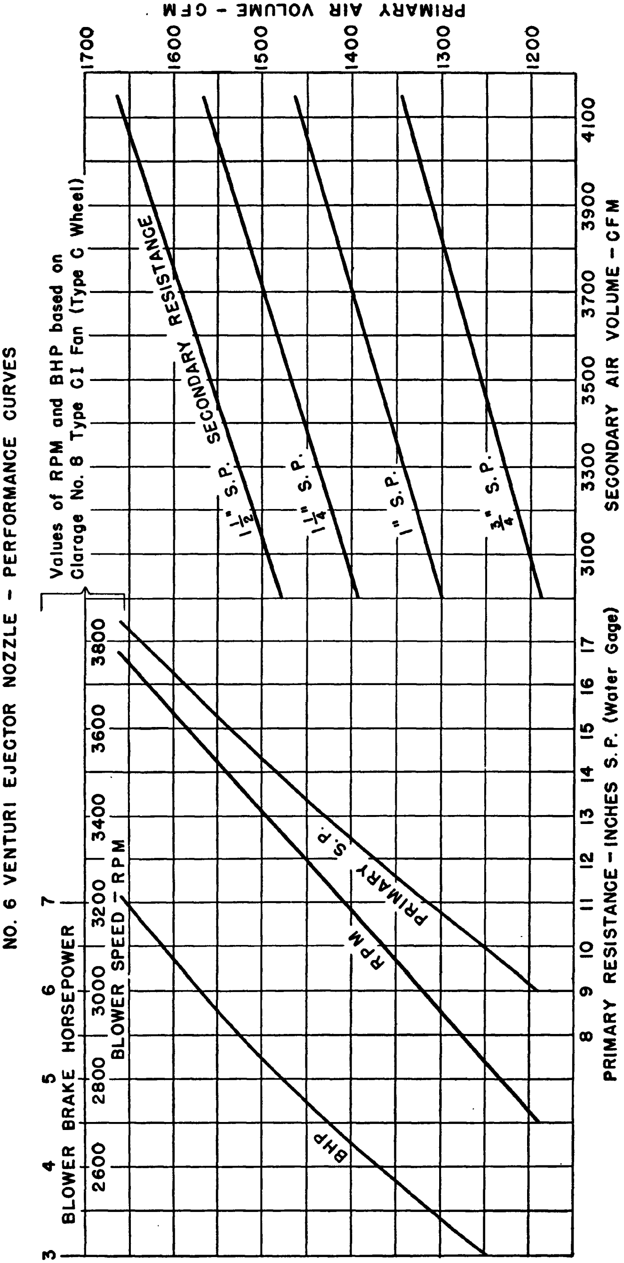


FIGURE 83. Curves for Ejector Calculations

CHAPTER IX

MEASURING AIR FLOW IN INDUSTRIAL VENTILATION

It was demonstrated in previous chapters that industrial atmospheric sanitation frequently involves air movement into hoods and air flow in ducts, collectors, fans, and the like. Consequently, it is a routine duty of the engineer to measure air velocity and air quantity; he must measure the velocity toward the hood at a source of contamination, the face velocity at a partially enclosing hood, such as a paint booth, and the volume rate of air flowing into or out of a hood, in a branch pipe, or in any part of a ventilating system. This presents no difficulty if the hood is regular and accessible and if the ductwork is accessible, straight, and fairly free from leaks. Such conditions are seldom met in industry, and the engineer must know "all the tricks of the trade" to get the best results with the least effort and with the least interference with production.

Measuring devices or meters in common use by engineers are of two general types—velocity meters and quantity meters. Velocity meters of interest to this group are rotating-vane anemometers, deflecting-vane anemometers, heated-thermometer anemometers, and the Pitot tube. Quantity meters are thin-plate or sharp-edge orifices and venturi meters. Other velocity meters sometimes used are katathermometers and hot-wire or heated-thermocouple anemometers. Their use is, however, not very widespread, and they will not be discussed here. Complete information on katathermometers and hot-wire anemometers may be found in references 97, 98, 99, 100, and 101. One other method of estimating rate of air flow, which is most useful to engineers, consists of measuring the suction in the duct leading from an exhaust hood and converting it to velocity by means of suitable conversion factors as will be explained later.

Velocity-Measuring Instruments. The *rotating-vane anemometer,* sometimes called the propeller or windmill anemometer, is one of the simplest instruments to use. It functions by measuring the linear feet of air passing in a measured length of time. Each instrument requires individual calibration to obtain accurate results. At low

velocities the friction drag of the mechanism is considerable, and therefore it is not recommended for velocities below about 200 fpm.[2] This instrument is particularly adapted for measuring the air velocity through large openings, such as spray booths, doorways, ventilating grilles, and the like, but not for small areas where the size of the instrument interferes with its proper manipulation or with the air flow. It is suitable also for metering the rate of air movement at some distance from exhaust or supply openings.

The *deflecting-vane anemometer* is a direct-reading instrument and has, therefore, many virtues not common to most of the other meters. Like the rotating-vane anemometer, it is not particularly accurate in the low-velocity range. Each instrument requires individual calibration and frequent checking, since an accumulation of dust on the vane will affect its operation. Two devices of this kind were made available commercially in recent years. One offers a number of calibrated accessory attachments which permit wide application in industrial ventilation measurements. The many uses of this instrument are shown diagrammatically in figure 84.

The *heated-thermometer anemometer*,[102] sometimes called the thermoanemometer (see figure 85), was developed about 1938 and was placed on the market shortly thereafter. It operates on the principle that the heat loss from an object at an elevated temperature is a function of the rate of air movement over the object. Hence, by employing an electrically heated thermometer with a measurable energy input and an ordinary thermometer, the air velocity can be determined from the temperature difference between the two thermometers. The heated-thermometer anemometer is unusual in that it serves to measure air velocities accurately over the entire range encountered in ventilation work. Each instrument must be calibrated individually. Because two glass thermometers must be located in the air stream to measure the velocity, breakage has been high, and therefore this device has not been accepted widely as a field instrument. Excessive breakage can be prevented if great care is exercised. For laboratory and similar work it is a very satisfactory meter. It is also particularly well suited to measure control velocities at some distance from exhaust hood openings and "drafts" near air inlets.

The *Pitot tube*[90] is the standard air-velocity meter and is used very widely. If it is carefully made it needs no calibration, although it is wise to have the instrument checked if unusual accuracy is required. The Pitot tube, when connected to a suitable pressure-indi-

cating device, such as commercial draft gages or U-tube manometers, serves to measure the velocity pressure created by air in motion. This device (see figure 86) consists of two concentric tubes, one

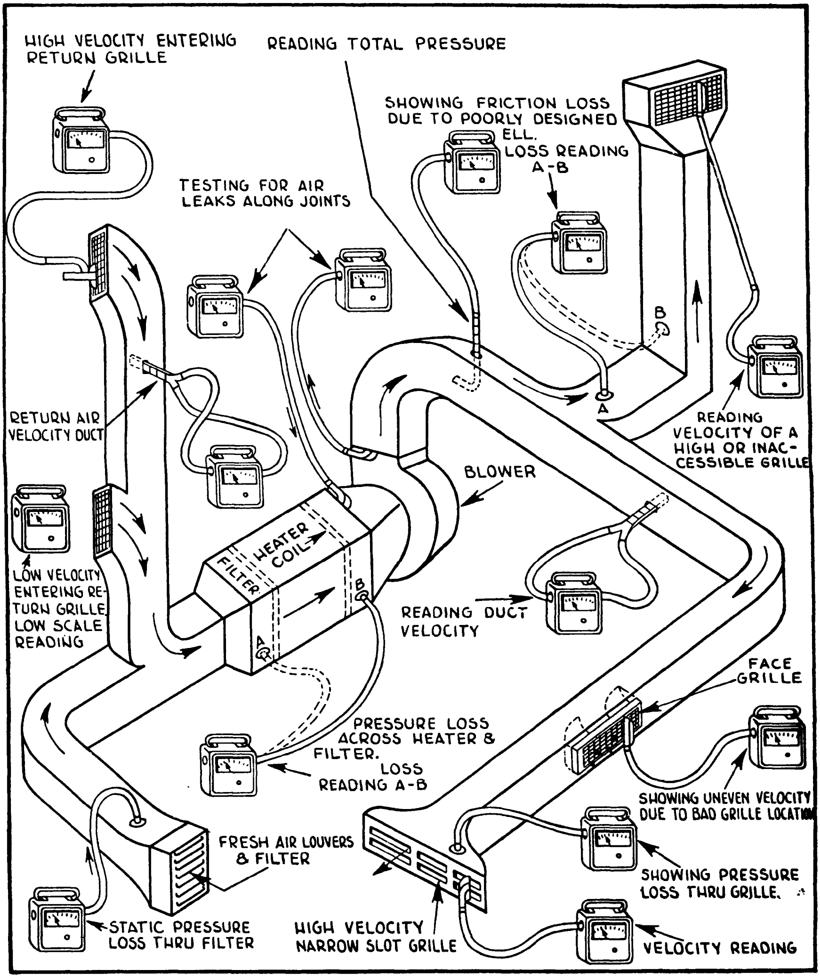


FIGURE 84. Uses of the Deflecting-Vane Anemometer (*Courtesy Illinois Testing Laboratories*)

serving to measure the total pressure existing in the air stream and the other to measure the resistance pressure only. When connected across a U-tube manometer or other suitable pressure-measuring mechanism, the resistance pressure is nullified automatically, and

only the velocity pressure is registered, from which the velocity can be computed.

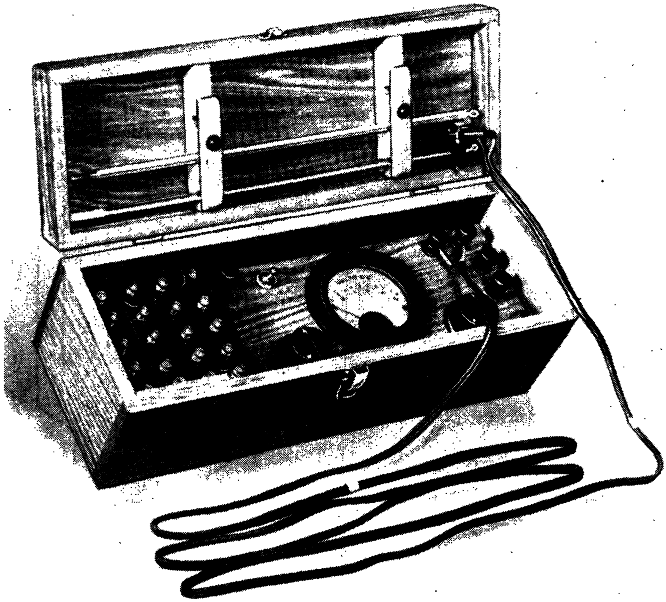


FIGURE 85. Heated-Thermometer Anemometer (*Courtesy Willson Products, Inc.*)

The Pitot tube makes use of a fundamental law of hydrodynamics

$$V = \sqrt{2gh} \tag{31}$$

where V = velocity in feet per second.
g = acceleration due to gravity (32.17 ft/sec^2).
h = pressure in feet of air.

Since h is usually measured in inches of water, and V is expressed in feet per minute, equation 31 for air at normal conditions of temperature and pressure (70° F and 760 mm hg) converts to

$$V = 4005\sqrt{VP} \tag{32}$$

where V = velocity in feet per minute.
VP = velocity pressure in inches of water.

This relationship has been plotted and is shown in figure 87, which is useful in determining V if the VP is known. Those preferring

tables should refer to table 12 in Chapter VI. It is evident from figure 87 and from table 12 that the Pitot tube is not practical for measuring low velocities in the field. Using a vertical U-tube manometer the accuracy is quite low for velocities below about 1300 fpm. With a carefully made and accurately leveled inclined manometer, velocities as low as 400 fpm can be determined satisfactorily, but field conditions usually preclude this procedure. For laboratory work, velocities of 100 fpm and lower can be measured accurately if

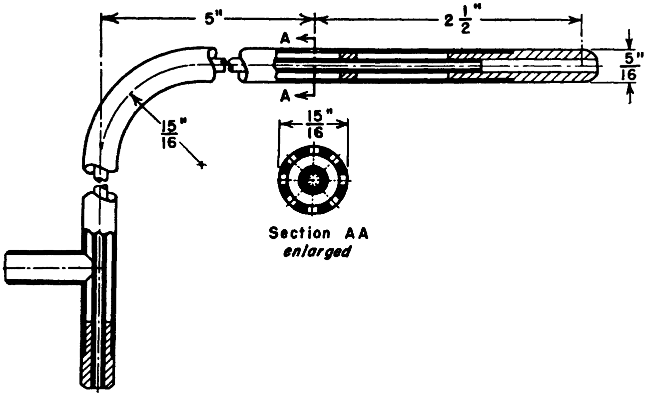


FIGURE 86. Pitot Tube

the *VP* is determined by means of special instruments such as the Wahlen gage,[103] a sensitive hook gage,[90] or a differential manometer.[104] Since the Pitot tube is not well suited for measuring low velocities under field conditions, its use is limited largely to determining velocities in ducts or at high velocity exhaust and supply openings.

Measuring Air Quantity. Velocity meters are used more frequently than quantity meters by engineers to determine the quantity (rate) of air flow in industrial or process ventilating systems. This is accomplished by one of the three following procedures, which are listed in the order of their popularity:

1. Measuring the average velocity in a duct by means of a velocity meter.
2. Estimating the velocity in a duct near an exhaust inlet by means of the suction.
3. Measuring the average inlet or outlet velocity by means of a velocity meter.

The Pitot tube, deflecting-vane anemometer, or heated-thermometer anemometer may be used to measure the average air velocity in a pipe or duct. Of these, the Pitot tube is most commonly employed.

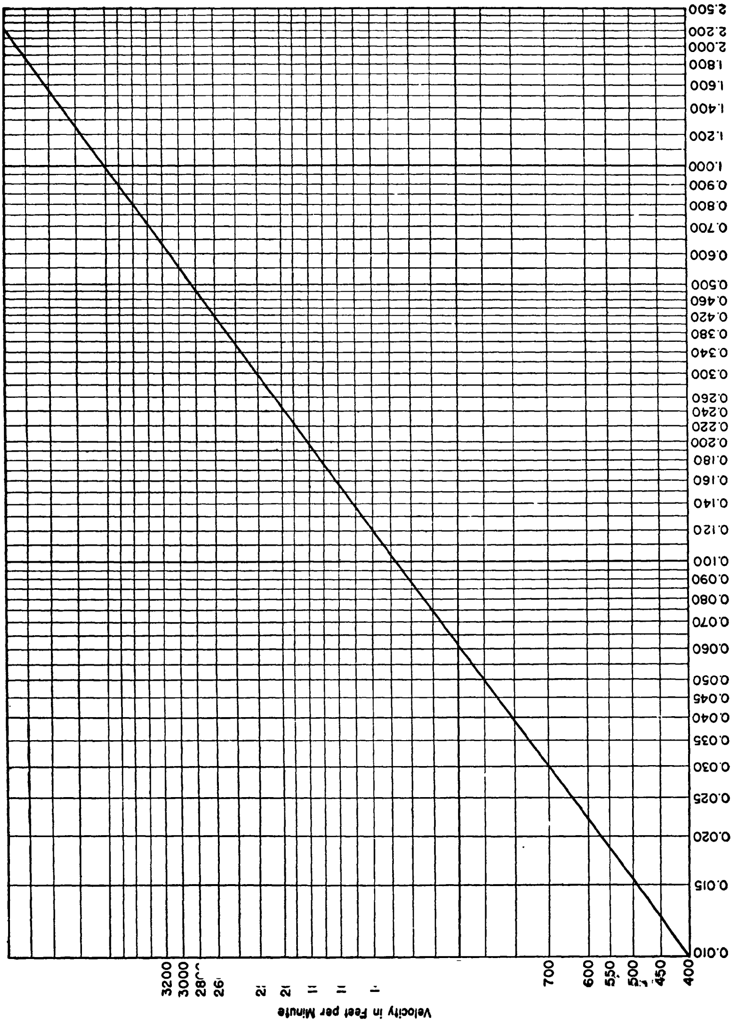


FIGURE 87. Velocity–Velocity-Pressure Relationship

The average velocity in a duct is determined by measuring the velocity at the center points of each of a number of equal areas and averaging these values. (NOTE. When using the Pitot tube it is important that the individual *velocities* be averaged, not the individual velocity pressures.)

Circular ducts under 12 in. in diameter are divided into three equal and concentric areas, and velocity readings are made at the center points of these areas as shown in figure 88. Circular ducts 12 in. and larger in diameter are divided into five equal concentric areas, and velocity measurements are made at the points listed in table 32.

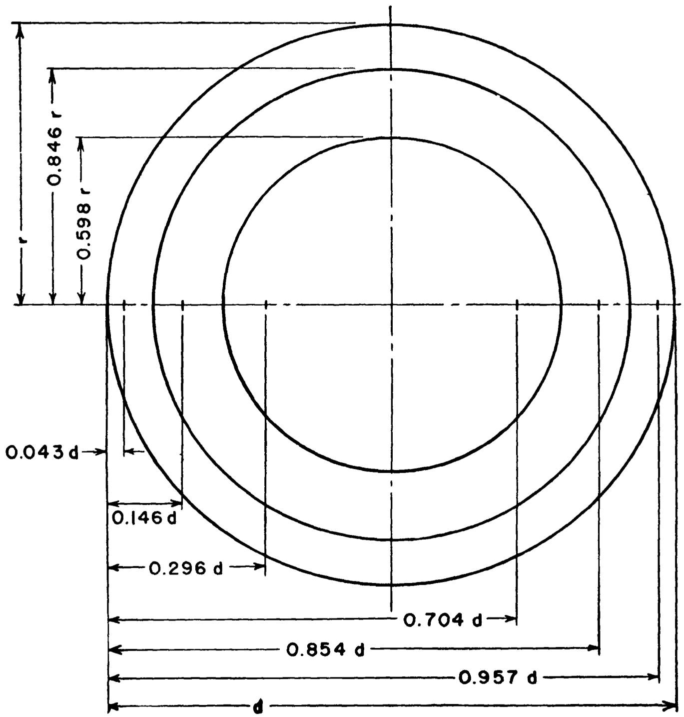


FIGURE 88. Locations for Velocity Determinations When Making a Six-Point Traverse

Velocity readings are made as far as possible downstream from a bend or other duct irregularity. It is advisable to make two velocity traverses at right angles to each other, except in those rare instances where the flow is known to be uniform. Having found the average velocity, the volume rate of flow in cubic feet per minute is determined by multiplying the average velocity in feet per minute by the duct area in square feet ($Q = AV$).

A fairly accurate estimate of the volume rate of air flow in circular ducts may be made from a single center line velocity reading if the measurement location is preceded by at least ten diameters of straight

TABLE 32

LOCATION OF POINTS FOR TEN-POINT TRAVERSE OF CIRCULAR OPENINGS OR DUCTS

Reading Number	*Distance from Wall to Point Where Reading is Taken in Terms of Opening or Duct Diameter*
1	0.026*d*
2	0.082*d*
3	0.146*d*
4	0.226*d*
5	0.342*d*
6	0.658*d*
7	0.774*d*
8	0.854*d*
9	0.918*d*
10	0.974*d*

duct. Under such conditions, the air flow frequently is fairly uniform across the duct, and the average velocity has been found by experience to be about 91% of the centerline velocity. This procedure is not recommended where accuracy is important and should be used only if a rapid traverse of the duct with the Pitot tube or other velocity meter indicates the flow to be essentially uniform. The volume rate of flow is computed by

$$Q = 0.91AV \tag{33}$$

where Q = quantity of air flowing in cubic feet per minute.
A = area of duct in square feet.
V = centerline velocity in feet per minute.

To determine the average velocity in *square* or *rectangular ducts*, the velocity is determined at the centerpoint of not less than nine equal areas and preferably more for larger ducts (more than about 12 in. on a side), as shown in figure 89, and these individual readings are averaged. The volume rate of air flow is then determined as for circular ducts.

In the foregoing and following discussions it is assumed that the reader is acquainted with the mechanics of making velocity determinations. If this is not the case, standard references, such as 105, 106, 107, and 108, should be consulted.

The *throat-suction* method for determining volume rate of air flow in branch exhaust pipes is very accurate if the suction measurement can be made one to three pipe diameters of straight pipe downstream from the throat of the exhaust inlet and if the hood or exhaust inlet

is amenable to accurate analysis as regards the coefficient of entry. This method is most useful to engineers since it provides a simple and accurate procedure if the conditions mentioned previously are met.

It was shown recently that the only important factors affecting the coefficient of entry for simple exhaust hoods (see figure 90) are the degree of taper or included angle and the size of the throat.[109] For rectangular hoods, only the major included angle need be con-

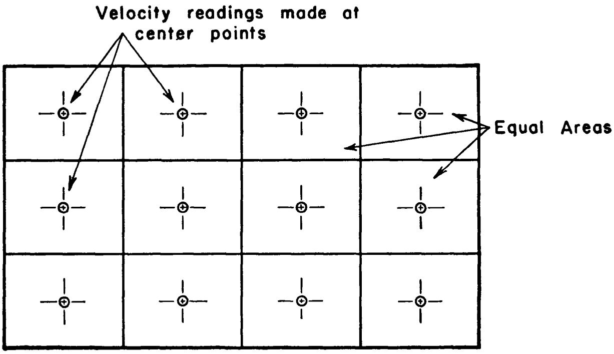
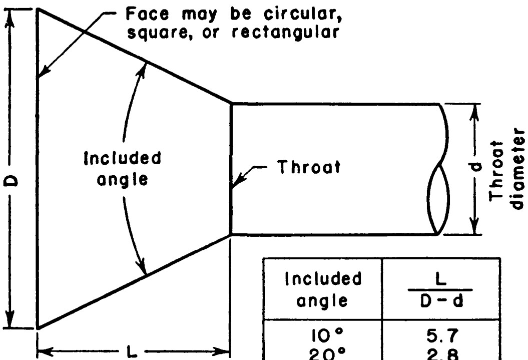


FIGURE 89. Example Showing Rectangular Duct Divided into Twelve Equal Areas for Velocity Determinations

sidered. For simple exhaust hoods, the coefficient of entry may be selected from figure 91, and for more complex shapes it may be estimated sufficiently accurately for field work from figures 31 to 43 and table 15 in Chapter VI. The included angle of the hood may be computed conveniently from data in figure 90. To determine the throat suction, one or more holes (preferably four, spaced 90° apart) not over 1/8 in. in diameter (preferably 1/16 in. or less) are drilled in the exhaust duct one duct diameter downstream from the throat for all hoods having tapers, and three duct diameters downstream from the throat for flanged or plain duct ends. The negative pressure is then read on a U-tube manometer which is connected to each hole in turn by means of a thick-walled soft rubber tube as illustrated in figure 92 or by means of a carefully calibrated deflecting vane anemometer as shown in figure 84. If the hood is followed directly by an elbow, or if other conditions prevent measuring the suction as suggested previously, it should be measured in a straight section of duct as close to the hood as possible (but not less than one duct diameter from the throat), and the reading should be corrected for

the interference. Thus, if an elbow intervenes between the hood and suction measurement location, the pressure loss caused by the elbow should be determined as explained in Chapter VI, and should be subtracted from the reading to give the suction produced by the hood and throat alone. Satisfactory results for most field work can



Included angle	$\frac{L}{D-d}$
10°	5.7
20°	2.8
30°	1.9
40°	1.4
50°	1.07
60°	0.87
70°	0.71
80°	0.60
90°	0.50
105°	0.38
120°	0.29
150°	0.13

FIGURE 90. Included Angle of Simple Exhaust Hood

be obtained by using 0.9 times the coefficient obtained from figure 91 if an elbow follows the hood, and the negative pressure is determined downstream from the elbow.

The volume rate of air flow is then determined by

$$Q = 4005CA\sqrt{h_s} \tag{34}$$

where Q = rate of air flow in cubic feet per minute.
C = coefficient of entry (from figure 91 or table 15).
A = area of duct in square feet.
h_s = suction in inches of water.

Results obtained by estimating the quantity rate of air flow using *velocity meters* at *exhaust* or *supply openings* may have considerable error unless the greatest care is observed. One reason for this is that the air stream does not fill the entire opening. Consequently, it is

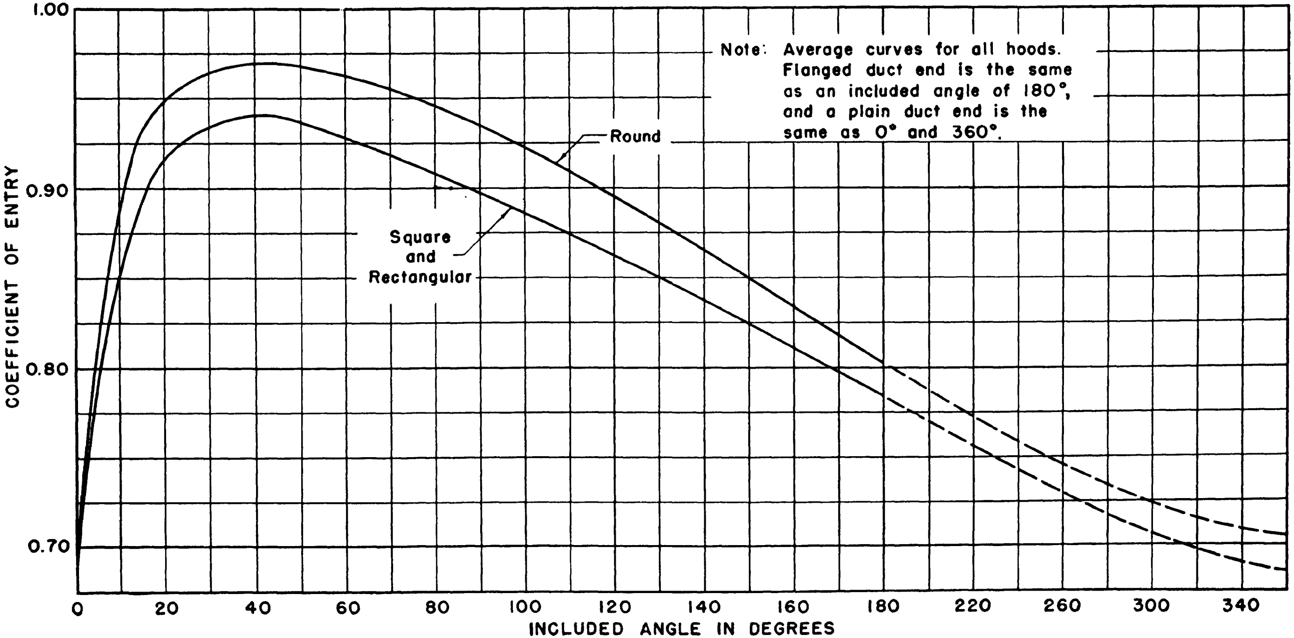


Figure 91. Coefficients of Entry for Exhaust Hoods

necessary to employ factors of flow which vary tremendously depending upon the nature of air flow (supply or exhaust), size of opening, nature of opening (flanged or unflanged), and the nature of the ap-

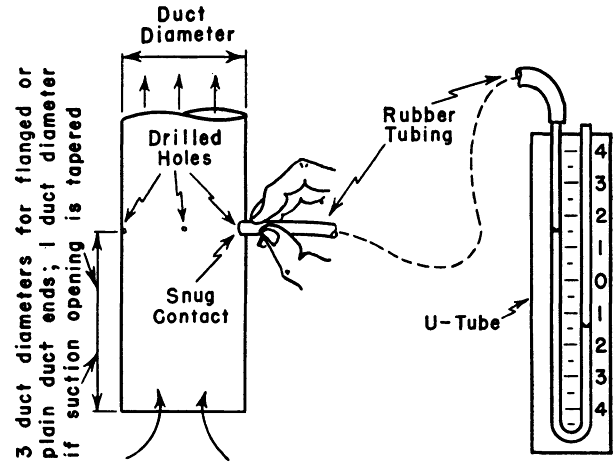


FIGURE 92. Measuring Static Head Near Throat of Suction Openings

proach duct for outlets.[110] Suggested flow factors are given in table 33 for different types of openings. If these factors are used judiciously, the results obtained by this method of quantity estimation should be accurate to within plus or minus 10%.

TABLE 33

FLOW FACTORS TO BE USED IN EQUATION 35 FOR DIFFERENT CONDITIONS OF AIR FLOW

Condition of Air Flow	*Flow Factor*
Flanged exhaust opening up to 4 sq ft in area	0.85
Flanged exhaust opening over 4 sq ft in area	1.00
Unflanged exhaust opening up to 1 sq ft in area	0.75
Unflanged exhaust opening 1 to 4 sq ft in area	0.85
Unflanged exhaust opening over 4 sq ft in area	1.00
Supply openings with straight length of approach duct equal to at least twice the smaller side	1.00

The average velocity through the opening is determined with any velocity meter in a manner similar to that described previously for obtaining the average velocity in a duct. The volume rate of air flow is computed by

$$Q = FAV \tag{35}$$

where Q = quantity of air flowing in cubic feet per minute.
F = flow factor from table 33.
A = area of opening in square feet.
V = average velocity of air flowing through opening.

The quantity of air flowing in a duct may be determined accurately by means of *quantity meters,* such as the thin-plate or sharp-edge orifice or the venturi meter.[105] The installation of these meters requires duct alterations with the resulting shutdown of the system, and they are seldom used for this reason. The venturi meter is considerably more difficult to construct and install than the orifice meter but has the advantage of a much lower resistance to air flow.

The volume rate of air flow in quantity meters is given by the relationship

$$Q = 0.00997 \left(\frac{CD_2^{\,2}}{\sqrt{1 - \beta^4}}\right) \sqrt{\frac{h_w}{\rho}} \tag{36}$$

where Q = volume rate of air flow in cubic feet per second.
C = coefficient of discharge.
D_2 = diameter of throat or orifice in inches.
β = ratio of throat or orifice diameter to pipe diameter.
h_w = pressure differential in inches of water.
ρ = density of fluid in lb/cu ft.

In *orifice meters,* the flow conditions through the metering device are affected by a number of factors, such as the velocity of flow and the ratio of the orifice diameter to duct diameter, as indicated in the foregoing equation. For orifice meters with flange taps (see figure 93), the influence of these conditions (the function $C/\sqrt{1 - \beta^4}$) has been determined experimentally.[105] These values are summarized in table 34 from which the appropriate one may be selected readily if the value of Reynolds number is known. Reynolds number is a dimensionless value which expresses the flow conditions in a channel or duct. For air it is calculated by

$$R = 8.4dV \tag{37}$$

where R = Reynolds number.
d = orifice diameter in inches.
V = velocity of air through orifice in feet per minute.

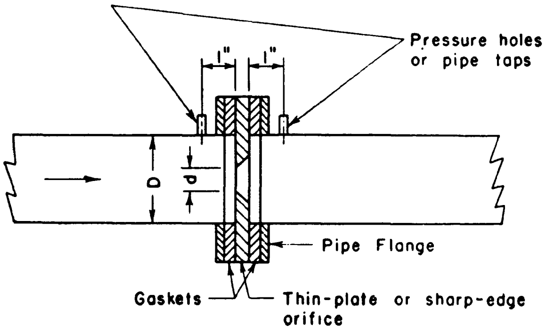


FIGURE 93. Thin-Plate or Sharp-Edge Orifice with Flange Taps

TABLE 34

VALVES OF K IN EQUATION 38 FOR DIFFERENT ORIFICE DIAMETER TO DUCT-DIAMETER RATIOS (d/D) AND DIFFERENT REYNOLDS NUMBERS *

(Letters keyed to figure 93)

$\frac{d}{D}$	*Reynolds Number in Thousands* 25	50	100	250	500	1000	10,000
0.100	0.605	0.601	0.598	0.597	0.596	0.595	0.595
0.200	0.607	0.603	0.600	0.599	0.598	0.597	0.597
0.300	0.611	0.606	0.603	0.603	0.601	0.600	0.600
0.400	0.621	0.615	0.611	0.610	0.609	0.608	0.608
0.450	0.631	0.624	0.619	0.617	0.615	0.615	0.615
0.500	0.644	0.634	0.628	0.626	0.624	0.623	0.623
0.550	0.663	0.649	0.641	0.637	0.635	0.634	0.634
0.600	0.686	0.668	0.658	0.653	0.650	0.649	0.649
0.650	0.717	0.695	0.680	0.674	0.670	0.668	0.667
0.700	0.755	0.723	0.707	0.699	0.694	0.692	0.691
0.750	0.826	0.773	0.747	0.734	0.726	0.723	0,721

* For duct diameters of 2 in. to 14 in. inclusive.

Letting K represent the function $C/\sqrt{1 - \beta^4}$, inserting 0.0749 for ρ (density of air at 70° F and 760 mm Hg), and converting to more conventional units, equation 36 becomes

$$Q = 21.8Kd^2\sqrt{h} \tag{38}$$

where Q = volume rate of air flow in cubic feet per minute.
K = coecfiient of air flow which varies with conditions as explained earlier (to be selected from table 34).
d = orifice diameter in inches.
h = pressure drop across orifice in inches of water.

This equation provides a simple and accurate means of computing the volume rate of flow through thin-plate or sharp-edge orifices with flange taps for air at 70° F and 760 mm Hg. For different conditions the rate should be corrected for density as indicated in equation 36.

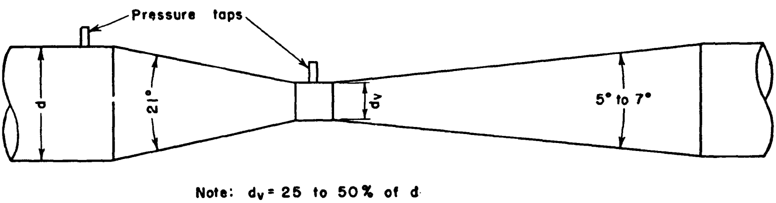


FIGURE 94. Venturi Meter

The usual design of a *venturi meter* is shown in figure 94. The ratio of the throat diameter (d_v in the figure) to the duct diameter (d) is kept between ¼ and ½. This ratio is designated by r in the following equation, which also was derived from 36:

$$Q = 21.2r^2d^2\sqrt{h} \tag{39}$$

where Q = volume rate of air flow in cubic feet per minute.
r = ratio of venturi throat diameter to the duct diameter (d_v/d).
d = duct diameter in inches.
h = pressure difference in inches of water.

This simplified equation also is accurate only for air at 70° F and 760 mm Hg. For other conditions, a correction for density must be made as indicated in 36.

OTHER AIR FLOW INDICATORS

While not quantitative devices, the *smoke tube, smoke bomb,* and *cigaret* serve a very important purpose in air flow studies. These devices show visually what is happening to the air.[111] If used to make a preliminary study before quantitative measurements are undertaken at openings or in rooms, smoke devices will frequently save much time in obtaining the desired data since the investigator will have a mental picture of the course the air is taking. More information on the nature of air movement into suction openings or in rooms can be obtained in less time through the use of smoke tubes than by any other single device or instrument. It has often been said, and not without reason, that if the industrial hygiene engineer were limited to one device or instrument for air-flow investigations he would choose the smoke tube.

The escape of contaminated air from exhaust hoods or exhausted areas which may be caused by eddy currents, interfering air currents, movements of workers or machinery, and the like is discovered more readily by means of some smoke than by any other method. Furthermore, such demonstration is frequently very helpful in convincing plant engineers or management that air may be escaping from a hood or enclosure even though it is under suction. The use of smoke bombs to show the nature of air flow into suction openings is illustrated very strikingly in figure 95. It is obvious from the figure that the flow into the hood is not uniform; witness the reversal of air direction at the second bomb to the right of the hood as compared to the symmetrically located one to the left.

Sometimes problems in air-flow measurement are encountered in which it is not possible to confine the air stream entirely and force it through a meter or past a definite velocity-measuring station. Under such conditions, the rate of air flow may be determined by the *dilution method* wherein a test gas is fed into the air stream at a known rate and, after thorough mixing has taken place, its concentration is determined in a unit volume of air.[112] The rate of air flow is determined by dividing the test-gas concentration into the rate of feed. The test gas must have the following properties:

1. Not absorbed chemically or physically in the ventilating system.
2. Not toxic or explosive.

3. Permit easy collection and determination, preferably continuous recording.

This method of air measurement using carbon dioxide as the test gas has been found particularly useful in studies of the exhaust ventilation requirements for certain industrial processes in which the principal factor controlling the ventilation needs is the rate of air displacement established by the process itself. An example is the discharge of crushed rock through a chute onto a conveying belt. The falling rock creates a flow of air which escapes from the point of feed onto the belt and disperses dust into the surrounding atmosphere. By introducing the test gas into the discharge chute and measuring its concentration in the air escaping where the rock falls on the belt, the rate of air flow created by the falling rock can be computed very readily, from which the required exhaust ventilation rate to control the dust can be computed.

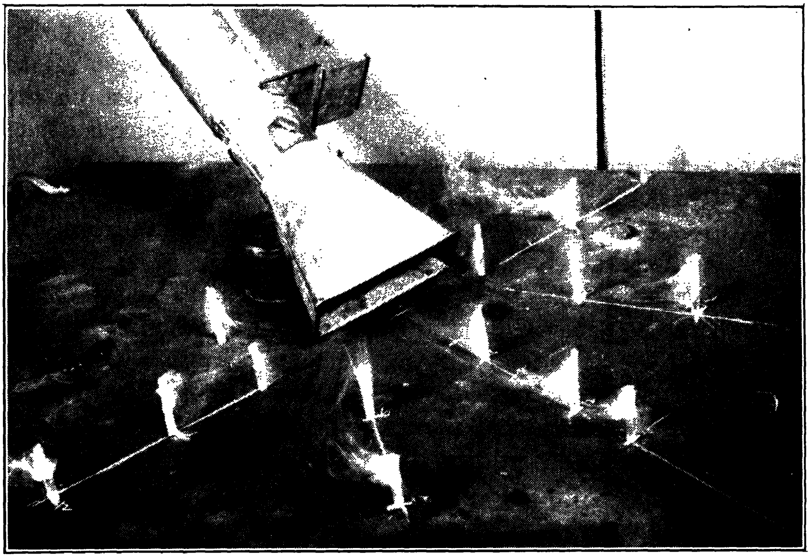


FIGURE 95. Smoke Bombs Indicating Nature of Air Flow (*Courtesy B. F. Postman*)

Even though this test procedure is of recent origin and has not yet come into widespread use, it is a most useful tool in the engineer's "kit" for measuring volume rate of flow at some operations where other methods are unsatisfactory.

CHAPTER X

CONTROL MEASURES FOR COMMON OPERATIONS AND FOR AN INDUSTRY

This chapter has been included for two definite purposes: (1) to provide plant management and engineers with information on the health hazards and their control at a number of operations common to many industries, and (2) to demonstrate to inexperienced or prospective industrial health engineers how complex is the engineering-control field—that no one control measure has any monopoly in industrial atmospheric sanitation. It is evident from previous chapters, particularly Chapter I, that not all operations which create health hazards are covered in this chapter. It was not intended that they should be; to accomplish such an undertaking would require volumes. Only a relatively few well-chosen examples, as required to fulfill the purposes stated above, are discussed.

The operations discussed are

1. Abrasive Cleaning (sand- and shotblasting).
2. Automotive Maintenance (under Garage Operations).
3. Buffing and Polishing.
4. Degreasing (under Metal Cleaning and Solvent Cleaning).
5. Electroplating (under Plating).
6. Forging.
7. Garage Operations.
8. Grinding.
9. Heat Treating.
10. Lead Working.
11. Luminous Dial Painting.
12. Metal Cleaning (degreasing and pickling).
13. Metal Spraying (Metalizing).
14. Painting (drying, brushing, and spraying).
15. Pickling (under Metal Cleaning).
16. Plating.
17. Polishing (under Buffing and Polishing).
18. Soldering.
19. Solvent Cleaning.
20. Trucking.
21. Welding (Electric and Oxyacetylene).
22. Woodworking.

Abrasive Cleaning. Abrasive cleaning or abrasive blasting may be carried out with sand or steel shot as the abrasive. The health hazard associated with steel-shotblasting operations is much less severe than with sandblasting operations, consequently, steel shot should be used wherever possible. However, if steel shot is not available or results in an inferior product, sand should be used and can be used safely if the necessary precautions are observed, as given later.

The potential health hazard in *sandblasting* operations is dust of a high free silica content. The maximum allowable concentration (mac) of free silica (SiO_2) is 5 million particles per cubic foot of air (mppcf), as determined by the standard light-field technique.

The dust hazard in sandblasting operations may be controlled by the following methods: (1) the use of properly designed mechanically exhaust-ventilated machines, cabinets, or rooms; (2) the use of personal protective devices; and (3) good housekeeping.

As a rule, production abrasive-cleaning operations can be carried out in mechanical devices such as enclosed tumbling barrels and rotary tables which are provided with adequate local exhaust ventilation. Wherever possible, devices of this nature should be used, and they should be maintained in good working condition so that their dust-control effectiveness is not impaired. The amount of air which must be exhausted from the various types of automatic abrasive-cleaning devices varies tremendously, depending upon a multitude of factors. In no instance, however, should the quantity of air exhausted be less than that required to produce a velocity of about 500 to 1000 fpm at all openings from which dust might escape.

Abrasive cleaning which requires manual operation may be carried out in small mechanically exhaust-ventilated cabinets which enclose the operation entirely with the exception of several holes in one wall to accommodate the hands and arms of the operator. Where possible, these access openings should be sealed with suitable flexible washers through which the hands may be inserted and which permit free movement of the arms for the operation. The precautions regarding maintenance and ventilation rate given in the previous paragraph apply for these devices also.

Large objects should be cleaned in suitable rooms or chambers which are provided with mechanical exhaust ventilation to prevent the dust from entering the surrounding atmosphere. These operations are usually conducted manually and the operator should be protected by means of a supplied-air respirator (abrasive-blasting

helmet) approved by the U. S. Bureau of Mines. Abrasive-blasting rooms and chambers should be provided with exhaust ventilation at such rate and in such fashion as to create an air velocity of at least 100 fpm downward or laterally through the room.

It is usually economical to collect the abrasive sand from the dust-collecting system for reuse. Whether or not this is done, the dust should be collected from the exhausted air before it is discharged to the outside, and the discharge outlet should be located at a point which will prevent the re-entrance of the contaminated air into the buildings. The filtered air should never be recirculated in the building. The discharge of the dust-collector hopper should be provided with a dust-tight flexible sleeve, which is attached to the top, or extends to the bottom, of the receptacle for the collected material, to prevent the escape of dust when the collector hopper is emptied.

Good housekeeping, which includes such items as keeping the floor, ledges, and machinery free of sand and dust, emptying the collector hoppers frequently and routinely, maintaining all connections through which dust or dust-laden air are conveyed in a dust-tight condition, and cleaning, sterilizing, and repairing the personal protective devices daily will aid considerably in keeping the dust concentration in the inspired air at a safe level.

The potential health hazards in *shotblasting* operations are metallic dusts and silica dusts in those instances where objects having sand on their surfaces are cleaned. The mac for some metallic dusts is 50 mppcf; for free silica dust, 5 mppcf, as determined by the standard light-field technique; and for lead dust, 0.15 mg per cubic meter of air (mg/m^3).

Even though the health hazard with shotblasting as a rule is much less severe than with sandblasting, the same general control measures are applicable. However, the various precautions need not be observed as rigidly as is the case with sandblasting.

Buffing and Polishing. These operations are done on power-driven wheels composed entirely or in part of textile fabrics, wood, felt, leather, paper, and the like and may be coated with abrasives and used for polishing, buffing, and light grinding purposes on the periphery of the wheel.

The smoke, dust, lint, and other atmospheric contaminants produced by buffing and polishing constitute largely nuisance and sanitation problems but may create a health hazard if the parts being processed are made of, or contain, lead or other highly toxic substance.

If the total buffing and polishing operations in a given room do not exceed the equivalent daily of one machine operating for two hours, no control is needed in most instances. If the amount of operations exceeds this figure the wheels should be provided with local exhaust ventilation. Data on hood design and required ventilation rate are given in Chapter XI.

Forging. This operation rarely creates a serious health hazard, but it always presents a potential hazard which should be recognized, namely, carbon monoxide and high temperature. The mac of carbon monoxide for an 8-hour daily exposure is 100 ppm.

Good natural ventilation should be provided in order to avoid excessively high temperatures, and this should be supplemented by mechanically operated exhaust fans in roof ventilators.

Canopy-type hoods with large diameter stacks should be employed over the furnaces, and, if the atmospheric concentration of carbon monoxide exceeds 100 ppm, this ventilation should be improved by the use of propeller type fans in the discharge stacks. The point of discharge should be so located that the exhausted air does not reenter any occupied buildings.

Propeller-type fans in these stacks will aid also in the maintenance of more suitable room temperatures.

Garage Operations. In the operation of any automotive-repair garage in which internal-combustion engines are operated to move vehicles, to tune or test the motors, or for "warm up" purposes, a serious potential health hazard is created by the carbon monoxide (mac 100 ppm) produced. This potential hazard, if uncontrolled, is especially dangerous in cold weather when the garage doors are closed and natural general ventilation is at a minimum.

The average idling automobile engine, if not in bad adjustment, produces carbon monoxide at the rate of about 0.6 cfm.[113, 114] Hence, to dilute the exhaust gas from a single automobile to a safe level requires a general ventilation rate of about 6000 cfm, assuming excellent air circulation to accomplish rapid mixing. On the other hand, more positive and less expensive control can be effected by removing the contaminant at its source. For small garages where motors are operated infrequently, the hazard can be controlled adequately by placing one end of a flexible metal tube (about 2 in. in diameter) over the automobile tailpipe and having the tube extend to the outside. Where motors are run more often or for longer periods of time, or where more than one motor may be operating at the same time, a local exhaust system, preferably with a properly located

underground tunnel serving as the main exhaust duct, is advisable. Equipment of this type is available commercially in which convenient connection can be made between the tail pipe and the exhaust duct by means of flexible metal tubing and floor-flush exhaust outlets. The exhauster should be sized on the basis of at least 100 cfm for each car which may be idling at one time.

Grinding. The potential health hazards associated with grinding operations are abrasive, metallic, and lead dusts. The mac of the abrasive and metallic dusts will vary with the chemical composition of the dust generated but should never exceed 50 mppcf as determined by the standard light-field technique. The mac of lead in the atmosphere is 0.15 mg/m^3.

Control in grinding operations should be accomplished by the use of wet grinding, general exhaust ventilation, local exhaust ventilation, or personal respiratory protective devices.

Wet-grinding operations do not require local exhaust ventilation. Good general room ventilation may be necessary if the operations are of such magnitude as to produce excessive mist and humidity.

Continuous *dry-grinding* operations should be provided with local mechanical exhaust ventilation. The exhaust hoods should be so located that the dust thrown off from the grinding wheels will be in the direction of the air flow into the hood.

Detailed information on hood design and recommended ventilation rates for different conditions are given in Chapter XI and in the Appendix.

Where portable grinders are used, particularly if lead-coated materials or materials containing considerable lead such as solder are being ground, U. S. Bureau of Mines approved respirators for toxic dusts should be worn if control by means of ventilation is either inadequate or impracticable.

Heat Treating. Most heat treating operations do not produce an important health hazard, but a potential hazard is always present. The principal potential health hazard is carbon monoxide (mac = 100 ppm). Other potential health hazards are cyanide and acrolein in certain types of heat treating. The currently accepted mac for hydrocyanic acid gas is 20 ppm and for acrolein, 1 ppm.

Heat treating furnaces should be examined periodically for defective equipment which would permit the escape of carbon monoxide into the workroom atmosphere. Partial control of carbon monoxide may be obtained by the use of suitable hoods enclosing the furnaces as much as possible and allowing the carbon monoxide and excessive

heat to be removed by convection currents. If the above control is inadequate, as shown by the presence of excessive concentrations of carbon monoxide, the exhaust ducts from the hoods should be equipped with fans to provide mechanical exhaust ventilation and thereby increase the rate of air removal sufficiently to maintain the atmospheric concentration of carbon monoxide within the maximum allowable limit.

The excessive room temperatures which are commonly met in heat-treating workrooms should be reduced by the use of natural ventilation where possible and by the use of roof ventilators equipped with mechanically operated exhaust fans.

Cyanide heat treating units should be controlled by the use of measures similar to those listed above.

The use of oil-quenching baths in connection with heat-treating operations presents possible hazards from acrolein, if vegetable oil is present in the quenching oil, and from carbon monoxide. The possibility of exposure to carbon monoxide is reduced by avoiding operation of oil-quenching baths at excessively high temperatures; that is, by controlling the temperature of the substance to be quenched. The use of mineral oil as a quenching material eliminates the possibility of exposure to acrolein.

Lead Working. The specific operations which will be considered under the heading of lead working are lead burning and lead melting. Lead burning is of two major types: (1) where lead in sheet or bulk form is installed in pipes, tanks, or vats for protection against corrosion, in rooms or around equipment for protection against X rays, and the like; and (2) where metal coated with a lead paint is welded as in repair operations or cut as in dismantling operations. Lead melting is meant to include all operations in which lead is melted to recover it or to process it, as in the printing industry. The principal health hazard from lead at burning operations is lead fumes; at melting operations, both dust and fumes may be encountered. The mac for an 8-hour daily exposure to atmospheric lead is 0.15 mg/m^3 of air.

When *lead burning* is performed continuously at a fixed location, as on a workbench, a system of downdraft ventilation should be installed, consisting of a grille-top workbench through which air is removed at a minimum rate of 200 cfm per square foot of grille area.

When lead burning is performed as a continuous operation, but where some variation of the site is necessary, local exhaust ventilation should be provided by means of an adjustable, flexible tube

with a mechanical source of exhaust ventilation. This tube should be 3 or 4 in. in diameter; the inlet should be located as close to the operation as practicable, and the source of exhaust should be sufficient to remove a minimum of 250 cfm of air from each operating site.

When lead burning is a temporary or occasional operation, the workers should be required to use respirators approved by the U. S. Bureau of Mines for protection against lead fumes (supplied-air, if possible, otherwise mechanical-filter).

Lead melting on a small or intermittent scale requires no control as a rule other than a thermostatic heat regulator, if done in a room with good natural ventilation. Very little fume is produced at the melting temperature of lead or slightly above, but the production rate increases rapidly if the temperature of the pot or furnace is permitted to rise above about 750° F. Consequently, if the lead temperature is prevented from reaching an excessive level, no hazard from fumes will exist. At large-scale melting operations, on the other hand, it is necessary to enclose the pot or furnace with a hood and to provide exhaust ventilation at the minimum rate of 100 cfm per square foot of all hood openings.

The principal source of atmospheric lead is in the removal of the dross from the melting pot or furnace and in the deposition of this dross in a haphazard fashion upon the floor in the vicinity of the melting furnace or the molds. The lead dross should be removed carefully and deposited in a suitable receptacle which should be closed whenever possible by means of a tight-fitting cover. If the melting operations are on a large scale it is advisable to provide an exhaust hood at the dross receptacle. In one large printing industry the melting furnace and dross receptacle were adjacent to each other and served by a common hood, an arrangement which worked very well.[55]

Luminous-Dial Painting. The potential health hazards in luminous-dial painting and in the storage and handling of radioactive luminous compound incidental to dial painting are radioactive dust, gamma rays, and radon, a gaseous decomposition product which is potentially dangerous when inhaled in excessive quantities. In addition to the commonly recognized luminous compounds, zinc sulfide which has been given fluorescent properties by exposure to radium should be handled with caution.

The exposure to gamma rays should never exceed the rate of 0.1 roentgen per 8-hour working day. The mac of radon gas in the atmosphere at any time is 10^{-11} curie per liter.

Control of *radioactive dust* and *radon* should be accomplished by (1) limiting the amounts of radioactive luminous compound issued to the workers, (2) partial or complete enclosure of processes, (3) the use of mechanical local exhaust ventilation, (4) general ventilation, (5) application of strict personal hygiene measures, and (6) personal respiratory protection.

Not more than the following amounts of radioactive luminous compound should be issued to each dial painter:

Luminosity (microlamberts)	Permissible Amount (grams)
0–12	20
12–38	10
38 or over	5

Where wet processing is impracticable in removing radioactive luminous compound preliminary to repair or refinishing, the article should be placed on a moist paper during the removal operation, and the worker should wear a supplied-air (air-line) respirator approved by the U. S. Bureau of Mines for protection against toxic dusts. Such respirators should be worn by all persons exposed to dust from radioactive luminous compound, including weighing and compounding activities.

The main sources of radon in radium-dial painting, handling, and storage operations are (1) the painting process itself and specifically from the paint stored in the container and being applied to the work, (2) the finished dials not yet removed to the drying cabinet, (3) the dials as they rest in the drying cabinet, (4) the storage cabinet preparatory to shipment, and (5) the storage cabinet at the point of use. Controls must be applied at these points.

Each dial-painting bench should be equipped with a transparent hood which encloses the bench with the exception of an open working face and which is exhausted mechanically at a minimum average rate of 50 fpm (100 fpm preferred) at the hood face. See reference 115 for hood specifications.

Cabinets in which painted dials are stored or dried should be ventilated at either of the following rates: (1) not less than 360 cfm per 1000 dials stored (2 to 10 pointers equivalent to one dial), and (2) not less than that sufficient to produce an average face velocity of 75 fpm across the cabinet doorway when the door is open.

In addition, general ventilation should be provided in all rooms in which radioactive luminous compound is used or handled so

that the radon content of the air in the room does not exceed 10^{-11} curie per liter.

Every employee should be instructed in the handling of radioactive luminous compound and in the observance of all rules that immediately affect or concern his conduct. Proper supervision of all workers should be maintained to insure the observance of these rules.

All dial painters and others handling radioactive luminous compound should change clothing before and after each day, observe strict personal hygiene, and be inspected by supervising personnel under ultraviolet light for traces of radioactive luminous compound whenever they leave the workroom. If any of the compound is detected on the skin or clothing it should be removed promptly.

If the exposure to gamma rays exceeds 0.1 roentgen per 8-hour working day per person, lead screening should be utilized to limit the exposure. The screening should conform to Failla's radium-protection chart.[116] It is well to bear in mind in this connection that gamma rays, unlike X rays, are not stopped very effectively by lead. In control, emphasis should be placed on having smaller quantities of the radioactive material near the workers and decreasing the radiant energy by increasing the distance between the material and the worker as much as possible.

Metal Cleaning. Even though abrasive cleaning is a metal-cleaning operation, the term as considered here embraces only degreasing and pickling.

The danger in *degreasing* operations results from atmospheric contamination by vapors of the degreasing solvents, such as trichloroethylene, ethylene dichloride, carbon tetrachloride, and other highly volatile solvents. The mac for an 8-hour daily exposure to vapors of trichloroethylene, ethylene dichloride, and carbon tetrachloride are 200 ppm, 100 ppm, and 100 ppm, respectively.

Degreasing operations should be carried out in properly designed tanks which may or may not be provided with local exhaust ventilation but should have adequate cooling or condensing capacity. The atmospheric contamination with the solvent vapors is usually low enough to present no health hazard when (1) the tanks are small (not over 10 sq ft in cross-sectional area), (2) the heat input and cooling capacity of the cooling coils are carefully regulated, (3) the tanks are located in large rooms with high ceilings and not near open doors or windows, (4) the withdrawal rate of the cleaned objects is slow (not more than 20 fpm), (5) an ample "free board" is main-

tained (minimum 4 in, 6 in or more preferred) to prevent "boiling over" and to reduce to a minimum the vapor carried out by room air currents, (6) parts to be degreased are supported in baskets or on frames in such position that the liquid solvent drains effectively, (7) degreased parts are not permitted to dry in room air, and (8) the general room ventilation is good.[71] However, for large tanks, or for any tanks located near open doors or windows or in small rooms, local exhaust ventilation at the tanks is necessary. The usual type of ventilation consists of slot-type lateral exhaust hoods located along one or both long sides of the tanks at the upper edge. (Additional information on hood design is given in Chapters V and XI.) The recommended minimum exhaust ventilation rate may be computed as follows:

$$Q = 50LW \tag{40}$$

where Q = the exhaust ventilation rate in cubic feet per minute.
L = the length of the tank in feet.
W = the width of the tank in feet.

The exhausted air should be discharged at a point outside the building where it cannot re-enter occupied buildings.

Tight-fitting covers should be employed on degreasing tanks whenever possible.

The cleaning out of degreasers, particularly those in which the workers must enter the tanks in the process, may involve exposures to excessive concentrations of solvent vapors for limited periods of time. Such exposures may be prevented by airing out the machine after withdrawal of the liquid and by the use of supplied-air respirators (air-line respirators or hose masks) approved by the U. S. Bureau of Mines when the exposures are severe and when their use does not impede the workers too greatly. Chemical-cartridge respirators do not afford adequate protection when the exposures are severe.

If the odor of solvent persists in the vicinity of the machine, or if the workers complain of ill effects, the concentration of solvent vapors in the atmosphere should be determined to ascertain the efficiency of existing controls. The atmospheric concentration of solvent vapors should not exceed the mac for the particular solvent used.

When the degreasing solvent is removed from the degreased object by a centrifugal process, the vapors should be kept from the room atmosphere by suitable means, such as enclosing the centrifuge and exhaust ventilating the enclosure at the minimum rate of 100 cfm

per square foot of opening in the enclosure. The opening in the enclosure obviously should not be in the line of throw of the centrifuge.

The solvent containers which are used to hold carbon tetrachloride or other solvents employed in small degreasing operations, such as wiping of metal parts, should be kept closed by tight-fitting covers whenever possible.

Even though trichloroethylene is essentially nonflammable and nonexplosive, it is unsafe to have open flames in the vicinity of trichloroethylene degreasers. An investigation of two explosions and fires near such degreasers indicated that the trichloroethylene was decomposed by the heat to form dichloroacetylene and hydrochloric acid and that the explosion and fires were due to the combustion of the dichloroacetylene, which is flammable.[117] This possibility must always be borne in mind, and repair operations involving welding at or near degreasing tanks should not be done unless adequate precautions have been taken.

Another item of concern to industrial health engineers in connection with heat or flames near degreasing operations involving chlorinated hydrocarbons is the production of a very irritating gaseous contaminant which has not yet been identified.[118] For a number of years it was believed that phosgene was formed under these conditions, but this assumption has slowly lost credence. All tests for phosgene were negative in the incidence reported in reference 118.

The potential health hazards found in *pickling* are acid mists, acid gases, and gases liberated because of impurities either in the pickling acid or the metal being cleaned. The mac in the atmosphere for some of these are

Hydrogen chloride	10 ppm
Hydrogen sulfide	20 ppm
Sulfur dioxide	10 ppm
Arsine	1 ppm
Phosphine	1 ppm
Nitrogen oxides	25 ppm

The acid mists and gases liberated during pickling operations should be prevented from entering the room atmosphere by enclosing or partially enclosing the tank if possible and by providing mechanical exhaust ventilation at the enclosure. The rate of ventilation should be sufficient to produce an air movement into the enclosure of at least 100 fpm at all openings. Where enclosure is not practicable, local exhaust ventilation should be provided at the

tank by means of slot-type hoods at the upper perimeter of the tank. The minimum required ventilation rate will vary with the nature of the operations but should never be less than 120 cfm per square foot of tank area. The exhaust system should be constructed of acid-resisting material and the exhausted air should be discharged at a point where it will not re-enter occupied buildings.

Pickling operators should wear acid-proof protective clothing and should practice good personal hygiene.

Metal Spraying (Metalizing). This operation subjects the sprayer and nearby workers to potential health hazards from metal fumes of all kinds and carbon monoxide. The mac for fumes of different metals vary from as little as 0.15 mg/m^3 for lead to as much as 15 mg/m^3 for zinc and even more for iron, and for carbon monoxide it is 100 ppm.

Metalizing as most commonly conducted is an infrequent, intermittent operation. Under such conditions no hazard will result unless the work is done in a small poorly ventilated room or if done with lead, cadmium, or other highly toxic metals. If the sprayed material is highly toxic, or if the operations are relatively frequent or on a large scale or production basis, the work should be done in properly designed exhaust booths similar to spray-painting booths. Exhaust ventilation should be provided at a minimum rate of 200 cfm per square foot of booth face, and the operators should always remain on the clean-air side of the object being sprayed.

Painting. In this category are included brush painting, spray painting, and paint drying. The potential health hazards associated with these operations are the toxic vapors of the paint solvents or liquid vehicles and the paint pigments for brush and spray painting. The toxicity of the paint thinners varies from the highly poisonous benzene to the relatively safe acetone; for the pigments it varies from the more toxic ingredients such as lead and antimony to the relatively harmless zinc and iron. Maximum allowable concentrations for many of the thinner and pigment ingredients may be found in table 1, Chapter I. Also, the approximate composition of many trade name thinners may be found in Table C of the Appendix.

The important methods for controlling the health hazards of *brush painting* are (1) the use of paints having relatively harmless solvents and pigments, (2) the use of adequate ventilation, (3) the use of suitable personal protective devices, and (4) good personal hygiene.

For the purpose of this discussion, only brush painting pertain-

ing to the repair or construction of buildings and equipment will be considered. Where brush painting is part of a production job, the control measures listed under spray painting should be applied.

Even though good ventilation is needed for brush painting of all kinds, special attention should be paid to the ventilation when paints containing the more toxic ingredients are used. Good natural ventilation provided by open doors and windows will suffice in large airy rooms, whereas some mechanical means such as a fan or blower will be needed to provide ventilation in small rooms where painting is being done.

For painting in small enclosed spaces, a supplied-air respirator approved by the U. S. Bureau of Mines should be used if definite mechanical ventilation is impracticable.

Good personal hygiene is very important in all manual painting. The hands and face should be kept clean by frequent and thorough washing, clothes should be changed frequently, dirty hands and soiled objects should be kept out of the mouth, and other items of personal cleanliness should be practiced.

The important methods for controlling the health hazards of *spray painting* are (1) the use of paints having relatively harmless solvents and pigments, (2) the use of mechanically exhaust-ventilated spray-paint booths and rooms, (3) the use of suitable personal protective devices, and (4) good personal hygiene.

All spray-paint booths and rooms should be mechanically ventilated at rates given below, and the discharge should always be located at a point where the contaminated air will not re-enter any building.

Spray painting should be done in mechanically exhaust-ventilated spray paint booths, preferably of the water-curtain type. The painting operation should be an automatic one on all production work, if practicable. The object being painted should be supported by a jig or other suitable mechanical device and should be located well within the confines of the booth.

Small spray painting booths (those having face areas of less than 4 sq ft) should have a minimum exhaust ventilation rate of 200 cfm per square foot of face area of the booth, whereas a minimum of 150 cfm per square foot of face area will suffice for larger booths. The air velocity should be essentially uniform across the entire face of the booth.

Downdraft exhaust ventilation through a grid-type floor is advisable in booths or rooms where cars, trucks, and other large

objects are spray painted. A minimum air velocity of 100 fpm toward the grids should be maintained at the painting location. However, for intermittent painting operations of this nature, any well-ventilated room is satisfactory if the worker wears, at all times while in the room, a supplied-air (air-line) respirator approved by the U. S. Bureau of Mines.

Whenever it is necessary for the painter to work downstream (as regards air movement) of the object being painted, or if the object being painted is large so that the painter is exposed to the paint mist, he should wear a supplied-air (air-line) respirator approved by the U. S. Bureau of Mines. Also all painters who use spray guns for painting in the repair and construction of buildings and equipment should wear approved supplied-air respirators at all times while painting.

In rare instances for intermittent operations, it will be found to be more feasible to provide the sprayer with a supplied-air hood covering the entire head than to provide the large amount of ventilation necessary to control the exposure adequately. In such cases, the use of supplied-air hoods is permissible.

Good personal hygiene as described under brush painting should be practiced.

Painted articles should be dried in enclosed drying ovens, rooms, or tunnels provided with mechanical exhaust ventilation. The air-removal rate should be sufficient to provide a minimum air velocity of 100 fpm across the face of all openings in the drying chamber. The point of discharge of the exhausted air should be so located that the vapors cannot re-enter any occupied building.

Detailed design information on ventilated painting booths is given in Chapter XI.

Plating. Operations involved in plating give rise to atmospheric contamination by chromic acid mists, metallic salts, cyanides, and other toxic gases. The mac for some of the materials which are encountered are as follows:

Chromic acid mist	0.1 mg/m^3
Arsenic (as arsine)	1 ppm
Hydrogen cyanide	20 ppm
Cadmium	0.1 mg/m^3

If toxic gases and mists are liberated in the electroplating process, as in chromium and arsenic electroplating and in some anodizing operations using dilute solutions of chromic acid and strong electric currents, local exhaust ventilation is necessary at the plat-

ing tank. A lateral-exhaust slot-type ventilating system removing at least 120 cfm of air per square foot of tank area is recommended. Where high current densities are used in anodizing or electroplating, much higher ventilation rates are needed to remove the air contaminant effectively. For proper functioning of the exhaust ventilating system, the level of the plating solution should be at least 4, and preferably 6, in. below the exhaust slots.

If toxic gases and mists are produced in the plating of cadmium, copper, and zinc, the above recommended exhaust ventilation system should be used.

The electroplating of zinc, copper, and nickel from acid or neutral solutions (noncyanide baths) does not give rise to toxic gases and mists and therefore does not require mechanical exhaust ventilation of the plating tank. However, good natural ventilation is recommended.

In those operations using a cyanide bath, care should be taken to avoid introduction of acid into the bath since hydrogen cyanide is liberated under these conditions. All cyanide baths should be conspicuously marked poisonous.

It is also essential that skin contact with the plating solutions be prevented. Care should be exercised to prevent splashing of the plating liquid.

More detailed information on all phases of safety in electroplating may be found in reference 70.

For a discussion of the health hazards connected with the cleaning process prior to electroplating, see "Metal Cleaning."

Soldering. The potential health hazards associated with soldering operations are lead fumes and hydrogen chloride gas from the acid flux. The mac for an 8-hour daily exposure to lead fumes in the atmosphere is 0.15 mg/m^3 and to hydrogen chloride gas, 10 ppm. Even if these contaminants are shown not to be present in harmful concentrations, soldering operations usually produce an acrid, irritating smoke which is decidedly objectionable to the operators.

Control measures should consist of local exhaust ventilation, general ventilation, or the use of personal respiratory protective devices, according to the nature of the operation. All soldering sites should have good natural ventilation, if possible.

Continuous or production soldering operations require local mechanical exhaust ventilation for the removal of lead fumes and acid gas. The workbench should be equipped with a grille top through

which the air is exhausted at the minimum rate of 100 cfm per square foot of grille area. In addition, the stove or heater for the iron should be enclosed on three sides in a hood which is exhaust ventilated at the rate of about 100 cfm per square foot of opening in the hood (see figure 96). The exhausted air should be discharged

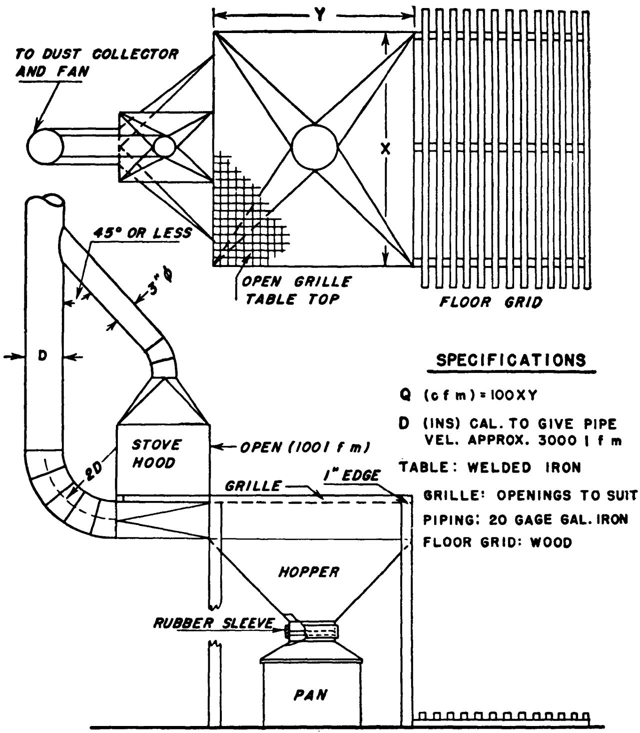


FIGURE 96. Exhaust-Ventilated Soldering Bench (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

to the outside atmosphere in such a manner that it will not re-enter the building.

For intermittent soldering operation of a repair nature, good general ventilation will control the exposure adequately.

For all operations which are done in confined spaces, adequate ventilation should be provided by any suitable means, such as a portable blower, fan, or air-operated ejector, or, if this is impracticable, suitable respiratory protective devices should be worn. If an acid-free flux is used, a mechanical-filter respirator approved by

the U. S. Bureau of Mines for toxic dusts will suffice; otherwise, an approved supplied-air (air-line) respirator will be needed.

Solvent Cleaning. Under this heading fall the many and varied, usually miscellaneous, operations, such as touch-up cleaning of finished parts, maintenance cleaning of equipment, and production cleaning of parts which it is impracticable to clean by immersion in degreasing tanks. The health hazard created by such operations is largely that of atmospheric contamination by organic vapors of the toxic solvents used in the cleaning operations. Common cleaning solvents are carbon tetrachloride, acetone, toluene, and gasoline, the mac of which are 100, 500, 200, and 1000 ppm, respectively. Other cleaners with their approximate make-up and toxicity are given in Table C of the Appendix.

Many maintenance cleaning operations such as type cleaning and equipment cleaning do not give rise to important health hazards owing to the fact that they are intermittent in nature and are frequently done in large rooms. Equipment or machine cleaning involving an hour or more per operation will create a serious hazard if done in small rooms or bays or if done in pits beneath automotive devices. All production cleaning or touch-up presents a potentially serious chronic health hazard and requires control measures.

For maintenance cleaning of equipment in small rooms, adequate control of the health hazard may be accomplished by means of local exhaust ventilation, general ventilation, or respiratory protection. For small pieces of equipment, local exhaust ventilation will serve satisfactorily, but usually the most practical measure is general ventilation produced by means of portable blowers with light-weight ductwork or tubes to convey uncontaminated air from the blower outside the room to the point or zone of operation. The air should be directed over the equipment or machine and away from the worker. By so doing the worker is not exposed to the high vapor concentrations, and the general ventilation provided to the room will prevent the room concentration from attaining a hazardous level. The volume of air needed can be determined by means of equation 1 in Chapter IV, since the amount of solvent per machine or per hour can be readily determined. The quantity of air actually supplied should be not less than twice that estimated on this basis and preferably should be four or five times the amount calculated.

Respirators can be used to protect the workers if the exposure periods are short (an hour or less), but general ventilation is the preferred method. If the vapor concentrations are not very high

(1000 ppm or less), chemical-cartridge respirators (twin-cartridge type) will suffice, but for higher concentrations gas masks or supplied-air respirators are recommended.

Most production cleaning or touch-up operations require mechanical ventilation to control the health hazard adequately. This is not necessarily true if the solvent is low on the scales of volatility (high boiling point) and toxicity and if the operation is done in a room with good air circulation and good general ventilation. Even in such instances, however, some mechanical ventilation is advisable

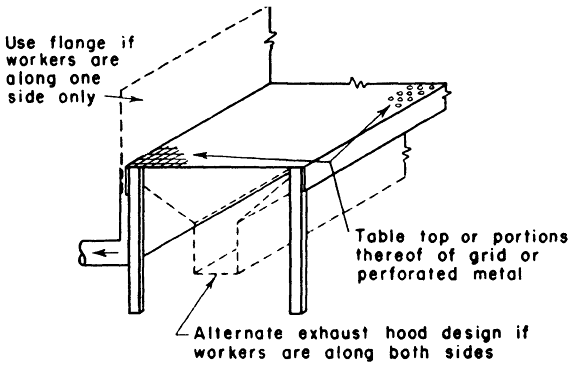


FIGURE 97. Downdraft Hood in Table Top

to avoid the consequences which would result from an accidental change to a more toxic or more volatile solvent. For cleaning operations of this nature, adequate ventilation may, as a rule, be provided at no great expense if the system is properly designed but not overdesigned.

Only a careful study of the problem will permit the best design. In general, local exhaust ventilation through partial enclosures, downdraft tables, or lateral exhaust hoods may be employed with better results than good general ventilation and air circulation. Adequate general ventilation, as determined by the equation cited earlier, with good air circulation, or preferably blowing tempered clean air over the cleaning operations and away from the operators, works well for individual or scattered operations.

Figure 97 shows the cross-sectional shape of one type of downdraft table for cleaning parts of relatively small size. The hood or duct beneath the table may be of any suitable shape to best accomplish uniform air flow and not interfere with the workers. Flanges

or partitions at the table top will improve the control considerably and should be employed if practicable.

If the parts to be cleaned are large flat solid objects or large sections of impervious materials, downdraft cannot be used since the object being processed closes off a large portion of the grille and nullifies the air-flow-control pattern in the area of vapor release. For such operations and for others where downdraft is not practicable, lateral exhaust ventilation with or without flanges may be used (see figure 98). The required ventilation rate of such hoods is given by equation 7 in Chapter V.

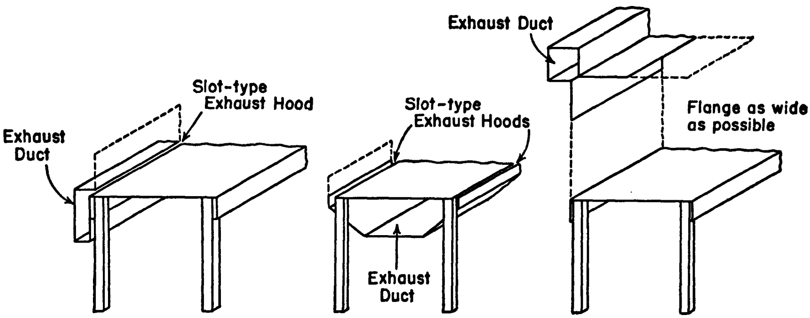


FIGURE 98. Lateral Exhaust Hoods at Work Benches

If the operations are such that they can be conducted in hoods or partial enclosures, better control is accomplished with lower exhaust ventilation rates since the area through which the control velocity must be maintained is smaller than with other types of hoods. In most production cleaning work, however, no great degree of enclosure is practicable.

Trucking. This term is meant to cover those operations in which an automotive truck or hoist powered with an internal-combustion engine is used to move other loaded vehicles about within a plant or to transport materials. One of the very common uses of such vehicles is to carry finished and packaged products from the packing room to the warehouse, shipping room, or freight car.

The potential hazard associated with these operations is that of carbon monoxide liberated by the engine. Under many conditions of operation, no health hazard is created, particularly if the engine of the truck is in good repair and operating efficiently, if the truck covers a large area and does not remain in one room for any great length of time, and if the general ventilation in all rooms frequented

by the truck is good. If these conditions are not met, the atmospheric concentration may exceed the safe value most of the time.

Experience has shown that this hazard can be controlled readily by (1) keeping the engine in good working condition, (2) extending the exhaust or tail pipe vertically above the truck operator's head as high as possible, and (3) making certain that the general ventilation rate is adequate to dilute the carbon monoxide concentration to a safe level. Since the tail pipe is hot while the engine is operating it is necessary to provide a suitable guard to prevent the operator and others nearby from coming in contact with it.

Welding (Electric and Oxyacetylene). The potential health hazards found in oxyacetylene and electric welding are fumes, gases, and infrared and ultraviolet radiation. On some welding or cutting operations, such as the repair of ships or other painted structures, severe exposures to lead may result from the paint or to mercury if mercury-containing antifouling paint had been used. Also where welding rods having fluoride fluxes are used, there is an exposure to hydrogen fluoride and volatile fluoride salts. The mac on the basis of 8 hours' daily exposure for some of the substances which may be encountered are

Mercury	0.10 mg/m^3
Lead	0.15 mg/m^3
Hydrogen fluoride	3 ppm
Nitrogen oxides	25 ppm
Zinc oxides	15 mg/m^3

Welding sites should be isolated from nearby workers by the use of screens or shields which protect the surrounding workers from the injurious light rays. At the same time these shields should not be more enclosing than necessary lest the ventilation at the welding site be reduced more than is desirable. Goggles, shields or helmets, and other necessary protective clothing should be worn by the welders to protect their eyes and skin from the infrared and ultraviolet radiation given off while welding.

The fume and gas hazard may be controlled by (1) ventilation, and (2) personal protection. Wherever practicable, local exhaust ventilation should be employed, and in other cases either general ventilation alone or general ventilation supplemented by respiratory protective devices is necessary. On routine operations, at more or less permanent locations or in places where continuous welding is done and conditions permit, local exhaust ventilation should be provided. For those operations where the welder moves about, a 3- or

4-in. flexible metal hose may serve as the hood and exhaust duct. Some systems are available also in which the flexible hose is counterweighted and the terminal end or hood is readily adjustable to any location. The minimum amount of air which must be exhausted from each welding operation is 250 cfm and may be as high as 1200 cfm where large amounts of fumes and gases are produced.[119] The exhaust hood should be kept as close to the operation as possible and should never be more than 12 or 15 in. away.

If welding is done in the open, natural ventilation is usually sufficient to prevent a health hazard. When welding in small enclosed spaces, the welder should wear an approved respirator of the supplied-air (air-line) type if adequate local exhaust ventilation is impracticable.

In many types of resistance welding, for example, seam and spot welding, ultraviolet and infrared rays are not produced. However, welding fumes and gases are produced. If the amounts of toxic material in the atmosphere near such operations exceed the maximum permissible safe concentrations, and if workers are located in these areas, sufficient local exhaust ventilation should be provided to control the hazard.

Woodworking. Practically every industry has its own carpenter shop in the maintenance department or in conjunction with one of the production operations such as packaging. Woodworking operations are actually seldom, if ever, of concern to the industrial hygiene engineer from the health hazard viewpoint since wood dust is not known to produce any illness except a form of fever or asthma to those who are allergic. However, wood dust, shavings, etc., are very flammable, and management is usually very receptive to dust control on these operations from the fire hazard standpoint. In fact, a fair percentage of the total local exhaust ventilation systems in existence today are on woodworking machinery.

The solution to the fire hazard from such operations is local exhaust ventilation. Details on hood design, exhaust ventilation rates, and plant layout are given in Chapter XI.

The preceding concerns scattered operations common to many industries. In some types of industries, one or more of the potential health hazards covered in this chapter may constitute the only occupational exposures, while in others the operations covered herein are minor indeed. Some industries, such as the granite, storage-battery, asbestos, foundry, and ceramic or pottery industries have significant degrees of atmospheric contamination in most depart-

ments. In the ceramic industry, for example, *without effective control measures,* excessive dust concentrations will exist in every major manufacturing section.[120] The recommended control measures for this industry by manufacturing department as formulated by the U. S. Public Health Service [121] and later corroborated by the N. Y. State Department of Labor [120] are summarized below since they demonstrate so well the variety of control measures which may be needed within one industry, and they point to the very important place which experience has in the industrial health engineering field.

Summary of dust control measures for the ceramic industry by department.

A. Raw materials handling and preparation
   1. Segregate from other departments, and segregate the materials storage bins from the batch-mixing room.
   2. Substitute mechanical handling equipment for manual methods, and enclose and ventilate such equipment.
   3. Employ bottom-dumping railway cars for bulk shipments.
   4. Purchase bagged materials in paper, rather than cloth, bags.
   5. Purchase materials with a specified moisture content at 3 to 5%.
   6. Perform hand shoveling operations carefully to minimize dust dispersion.
   7. Enclose and ventilate all weighing, dry mixing, crushing, grinding, and screening operations, including all loading and discharge points, manual as well as mechanical.
   8. Separate wet milling, pugging, filtering operations from other raw materials handling, and conditioning.

B. Shaping of article
   1. Require workers to change clothes daily.
   2. Place shields around jiggers and turning operations to reduce spattering.
   3. Provide impervious surfaces on work benches with grilles above hoppers for catching clay scraps.
   4. Wash ware boards daily.
   5. Provide exhaust ventilation for all fettling, drillers, and other greenware finishers.
   6. Provide exhaust ventilation on dry presses.
   7. Substitute mechanical equipment for supplying powdered materials to presses for manual methods.
   8. Provide exhaust ventilation on insulator lathe turning.

C. Mold shop

   Segregate mold shop from other manufacturing departments.

D. Kiln department
   1. Substitute quartz-free bedding materials for flint, and use coarse, dust-free materials.
   2. Recondition coarse bedding materials to remove fines.
   3. Provide exhaust ventilation at bedding and sagger unloading stations if fine bedding material, particularly flint, is used.

4. Provide exhaust ventilation on all fired-ware cleaning and shaping operations.

E. Glaze department
1. Use glazes containing low solubility lead, i.e., fritted glazes. (For dust control in glaze preparation, see raw materials preparation.)
2. Wash ware boards daily, and use only in glaze department.
3. Clean continuous driers daily with water.
4. Maintain good housekeeping at all glaze-dipping operations, and change clothes daily if glaze contains soluble lead in significant amounts.
5. Enclose and ventilate all glaze-spraying operations.
6. Provide respiratory protection for all sprayers working in booths, tanks, or other confined spaces.
7. Provide exhaust ventilation for dusting tables.

Similar complete industrial hygiene studies have been made in other industries, particularly some of those involving considerable dust production. Examples are (1) the granite industry;[21] (2) the explosives-manufacturing, loading, and storing industry during World War II;[48] (3) the storage-battery industry;[122] (4) the anthracite mining industry;[123] (5) the asbestos industry;[20] (6) the manganese ore-crushing industry;[22] (7) the felt-hat industry;[124] (8) the nonferrous-metal mining industry;[125] (9) the foundry industry;[126] and (10) the granite and marble memorial industry.[127]

CHAPTER XI

EXHAUST SYSTEMS—SPECIFIC DESIGN DATA AND ILLUSTRATIONS OF INSTALLATIONS

It is obvious from previous chapters that there are many industrial operations producing harmful or objectionable atmospheric contamination for which there is, and can be, no "cut and dried" control procedure. An attempt has been made, however, to present the fundamentals of control which will serve to guide or assist the engineer in selecting and devising suitable control measures.

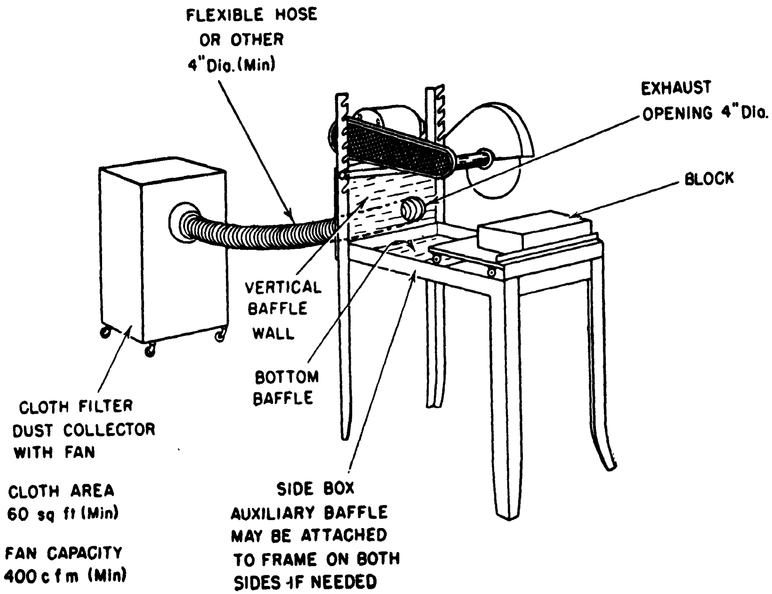


FIGURE 99. Dust Collector for Clipper Saw (*Courtesy Industrial Hygiene Foundation*)

There are, on the other hand, a number of contaminant producing or liberating types of operations and processes for which standard control measures and design data have been developed which are applicable to the large majority of such operations. Design data for some of these types of operations will be presented in this

chapter. Data on other operations are summarized in Table E of the Appendix. The operations or processes to be covered are

1. Cutting bricks and refractory shapes.
2. Finishing tanks.
3. Grinding, buffing, and polishing.
4. Production painting.
5. Stone cutting.
6. Tumbling mills.
7. Woodworking.

Cutting Bricks and Refractory Shapes. The portable saw used for cutting bricks and refractory shapes in many industrial opera-

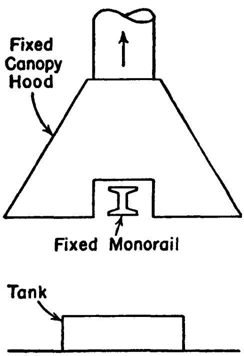


Figure 100. Canopy Hood—Stationary Type (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

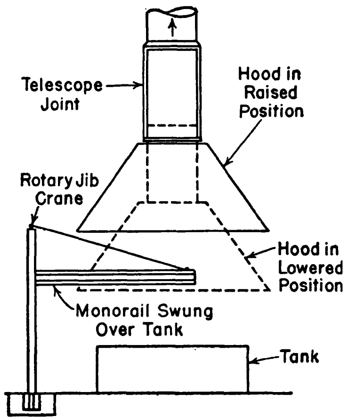


Figure 101. Movable Canopy Hood for Raising Out of Position (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

tions is a troublesome source of dust. If the material being cut contains free silica, a potential health hazard is created. In any event, the dust so created is a nuisance.

Since the saw is portable it is impracticable to equip it with appropriate exhaust ventilation for discharge to the outside or for connection to another exhaust ventilating system. It is, therefore, necessary to provide it with a unit exhaust system which incorporates a collector for removal of most of the collected dust. A satisfactory design is shown in figure 99. The filter and exhauster unit

should have a capacity of 400 cfm. The exhaust duct (a 4-in. flexible metal hose) is connected to a baffle at the rear frame of the machine. The baffles beneath and behind the saw table serve to confine the dust. Since the air is recirculated into the workroom it is necessary that the unit collector have a high filtering efficiency.[128]

Finishing Tanks. In this group are included such tanks as plating, pickling, degreasing, lacquering, Parkerizing, anodizing, and caustic cleaning tanks. Not all such tanks need local exhaust ven-

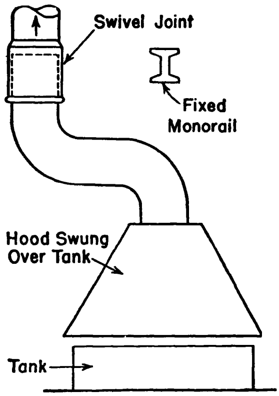


FIGURE 102. Movable Canopy Hood for Swinging Out of Position (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

tilation under all conditions. Additional information on this point for some types of tanks is given in the preceding chapter. Under certain conditions, however, local exhaust ventilation may be needed, and design data for such cases is given in this section. The best guide as to whether local exhaust ventilation is needed or not is the presence or absence of excessive concentrations of harmful materials in the air in the vicinity of the tank. This is determined by methods outlined in Chapter II.

One very common method of providing local exhaust ventilation at tanks is by means of *canopy hoods,* especially if the liquid in the tank is substantially above room temperature, if the workers seldom have their faces over the tank or in line with the rising contaminated air, and if the hood does not interfere with the operation of overhead cranes. The required ventilation rate is as given in Chapter V for hoods of this type, and the duct velocity is in the 2000- to 3000-fpm range. The usual fixed-canopy hood design is

shown in figure 28, Chapter V, and figure 100. The slope of the sides from the horizontal is in the range of 30 to 45°. Variations as shown in figures 101 and 102 will overcome the frequent objection of being in the way of operations and will permit very low ventilation rates for tanks which require only infrequent attention by operating personnel.

The most common type of local exhaust ventilation for finishing tanks is *lateral exhaust.* For narrow tanks (up to about 20 in.)

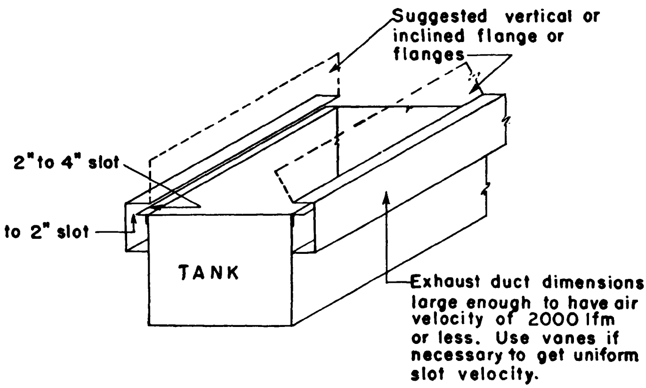


FIGURE 103. Slot-Type Exhaust Hoods for Tanks

satisfactory performance can be accomplished with an exhaust hood along only one long side of the tank. For greater widths, the hoods should be located along both long sides and preferably around the entire perimeter. The common design is shown in figure 103. Flanges are helpful if permissible. Other designs especially adapted for hot liquids and operations where vapors escape from the processed parts as they are removed from the tank are shown in figures 104 and 105. For wide tanks where hoods are not permissible along the tank a design as shown in figure 106 may be used. The hood beyond the slot (the plenum) and the duct are sized for air velocity of about 2000 fpm. Recommended exhaust ventilation rates are

For degreasing and lacquering	50 cfm per square foot of tank area
For plating	120 cfm per square foot of tank area
For hot solutions	150–250 cfm per square foot of tank area

Frequently the volume of air exhausted to accomplish control especially at heated or plating tanks creates a heating problem in cold weather. To prevent this, it has been suggested that the exhausted air or a substantial part of it be unheated and supplied at an appro-

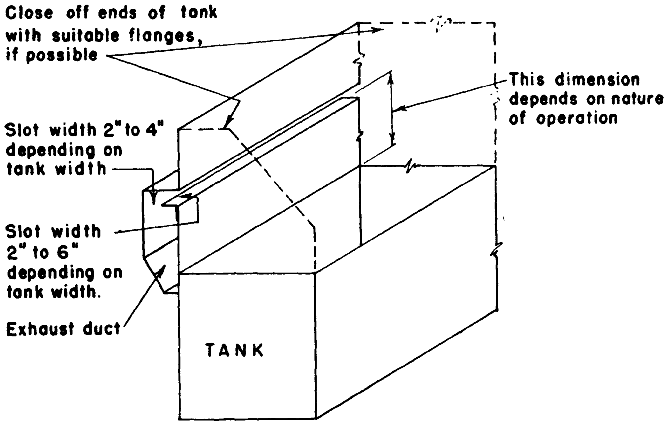


FIGURE 104. Exhaust Hood for Hot-Liquid Tanks and Similar Tanks Where Vapors Escape from Parts Being Processed Above Tank Top

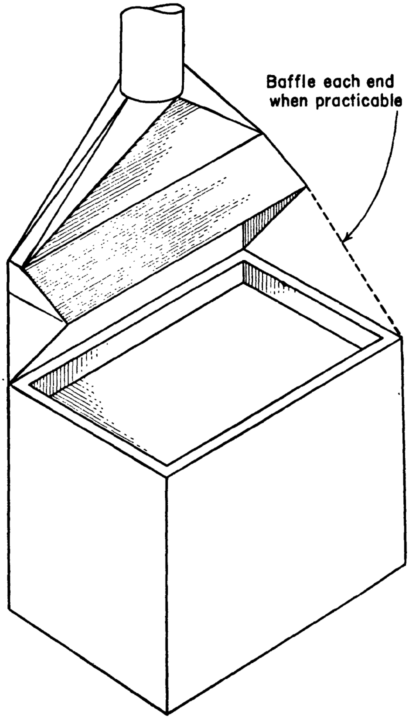


FIGURE 105. Semilateral Exhaust Hood (*Courtesy Connecticut Department of Health*)

priate location near the tanks.[129] Two methods of doing this are illustrated in figure 107. Another procedure which has been found to work well in at least one case is shown in figure 108.

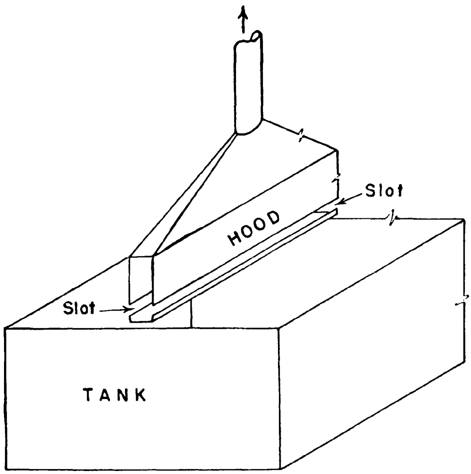


FIGURE 106. Slot-Type Exhaust Hood at Middle of Wide Tank

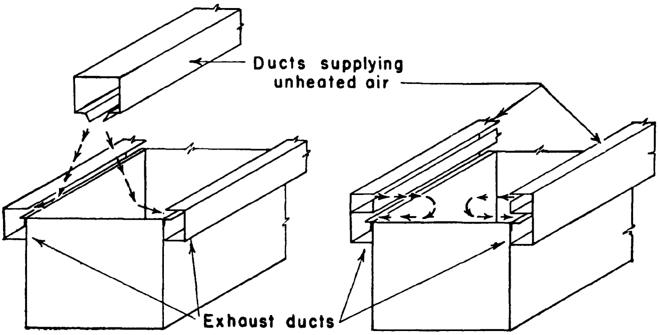


FIGURE 107. Supply and Exhaust System of Tank Ventilation

For situations where the heat loss is no problem but exhaust hoods cannot be located along both long sides of the tank, a "push-pull" system may be used. One type of design is shown in figure 109. The positive air curtain could be supplied through a very narrow hood or slot in a duct instead of the pipe shown in the figure. It has been found that with 8 cfm of air supplied per foot of tank length at a pressure of 7 in. of water through $\frac{3}{16}$-in. diameter holes

in a $1\frac{1}{2}$-in. pipe, better control was accomplished on wide tanks with an exhaust rate of 90 to 140 cfm per square foot of tank surface than with 200 to 250 cfm, when exhaust alone was used.[130]

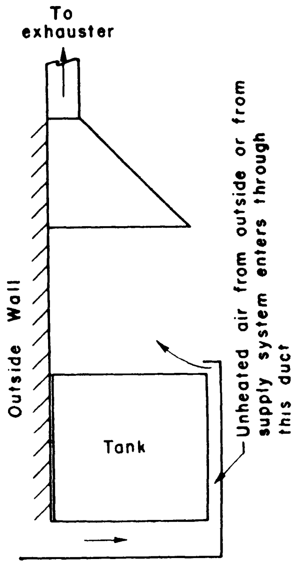


FIGURE 108. Supply and Exhaust System of Tank Ventilation

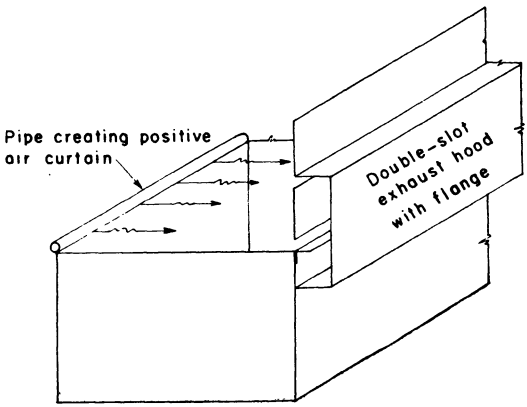


FIGURE 109. Push-Pull System of Tank Ventilation

Grinding, Buffing, and Polishing. In this group are included all grinding, buffing, and polishing operations in foundry, machine, and allied industries. Dust control at such operations is not always

needed (see also Chapter X). However, wherever control is needed, as determined by the existence of an objectionable or harmful atmospheric condition due to such operations, local exhaust ventilation should be installed in conformance with the specifications summarized in this section.

There are many different types of grinders, buffers, and polishers, which require a variety of hoods. Not all these different hoods can be illustrated here, but a few of the more important ones are shown

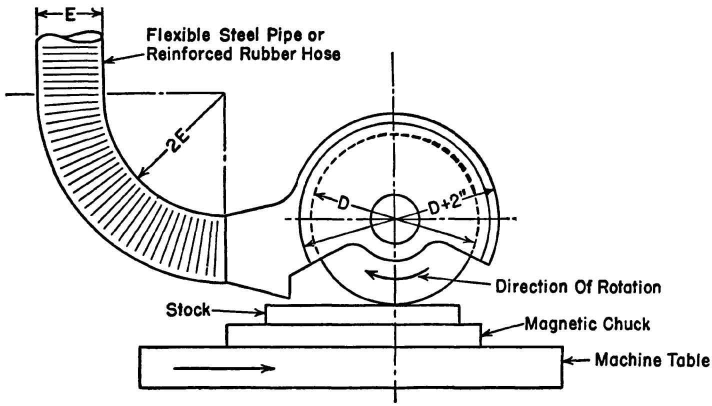


FIGURE 110. Local Exhaust at Dry Surface Grinder (*Courtesy AFA*)

in figures 110 to 116. Illustrations of other designs may be found in reference 131 and in Figures V, VI, and VII of the Appendix.

The volume rate at which air must be exhausted depends upon the type of operation and the size of the wheel or belt used. Since the recommended duct velocity is 4500 fpm, different size exhaust hood outlets are required for the different operations and for different-sized wheels of the same operation. Data on size of exhaust outlet at the hood and recommended exhaust ventilation rate for the different types of operations and for different-sized wheels are given in table 35.

Production Painting. Painting of finished parts is an important operation in many industries. In addition to other preventive measures, such as using paints having relatively nontoxic thinners and pigments, local exhaust ventilation is usually needed to control the health hazard adequately. The design of such systems for dip or immersion coating was covered earlier in this chapter; this section will be devoted to the design of paint spray booths.

TABLE 35

Exhaust Outlets and Ventilation Rates for Grinding, Buffing, and Polishing Wheels and Belts of Different Sizes

Type of Equipment	Wheel or Belt Dimension (inches)	Hood Exhaust Outlet Diameter in Inches									
		3	3½	4	4½	5	5½	6	6½	7	8
		Exhaust Ventilation Rate in Cubic Feet per Minute per Outlet									
		220	300	390	500	610	740	880	1040	1200	1560
Grinding and cut-off wheels	Diameter	<9	—	9–16	16–19	19–24	—	24–30	—	30–36	
	Width	1½	—	2	3	4	—	5	—	6	
Buffing and polishing wheels	Diameter	—	<9	—	9–16	16–19	19–24	—	24–30	—	—
	Width	—	2	—	3	4	5	—	6	—	—
Horizontal single spindle discs	Diameter	<12	—	12–19	—	19–30	—	30–36	—	—	—
Horizontal double spindle discs	Diameter	—	—	—	—	<19	—	19–25 30–53 (2 outlets)	—	25–30	53–72 (4 outlets)
Vertical single spindle discs (not covered)	Diameter	—	—	<20 (2 outlets)	—	—	20–30 (2 outlets)	30–53 (4 outlets)	—	53–72 (5 outlets)	—
Vertical single spindle discs (more than half covered)	Diameter	—	—	20–30 (2 outlets)	<20	—	—	30–53 (2 outlets)	—	—	53–72 (2 outlets)
Belts and straps	Width	<3	3–5	5–7	7–9	9–11	11–13	—	—	—	—

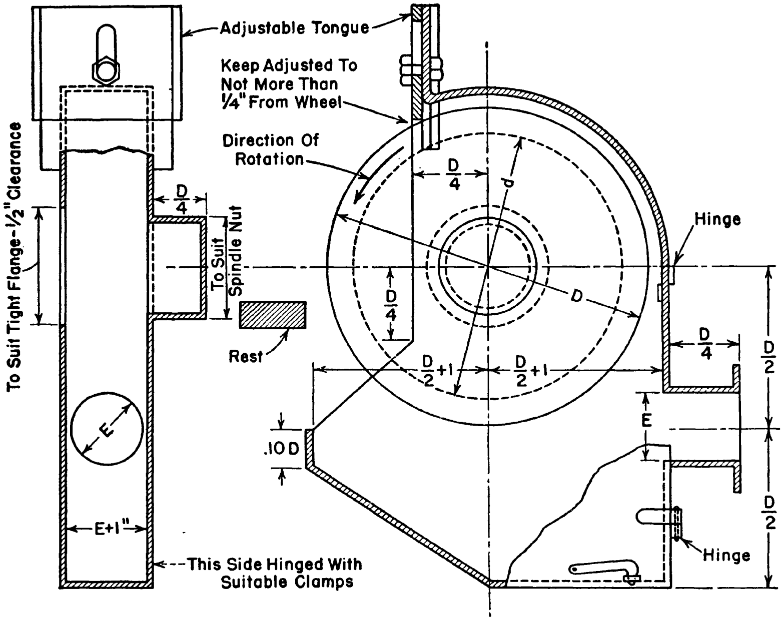


FIGURE 111. Standard Grinder Hood (*Courtesy AFA*)

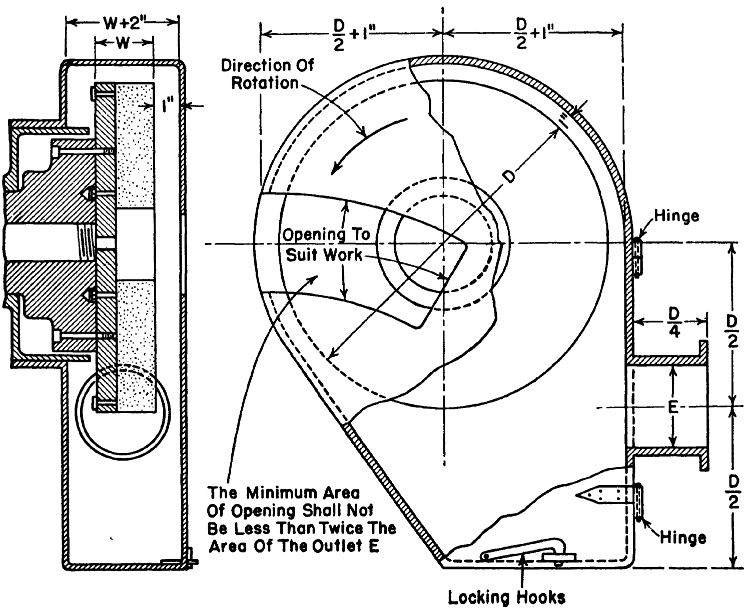


FIGURE 112. Horizontal Single-Spindle Disc-Grinder Exhaust Hood (*Courtesy AFA*)

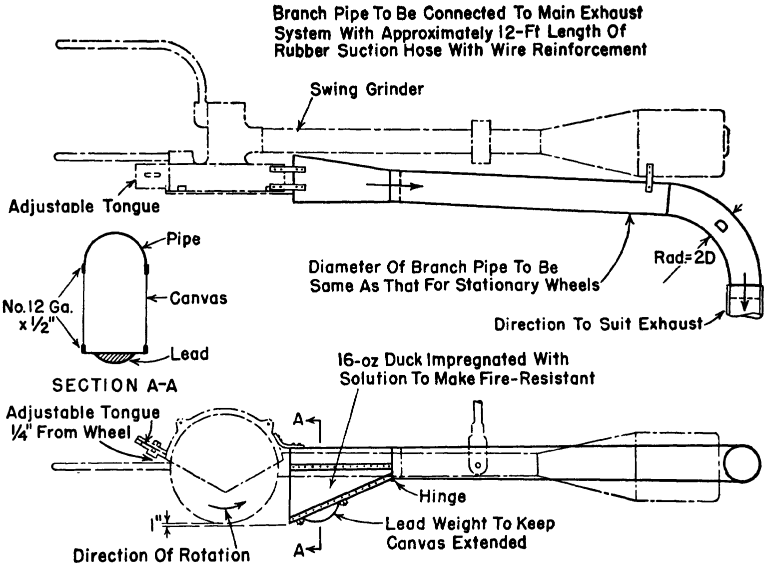


FIGURE 113. Local Exhaust at a Swing-Frame Grinder (*Courtesy AFA*)

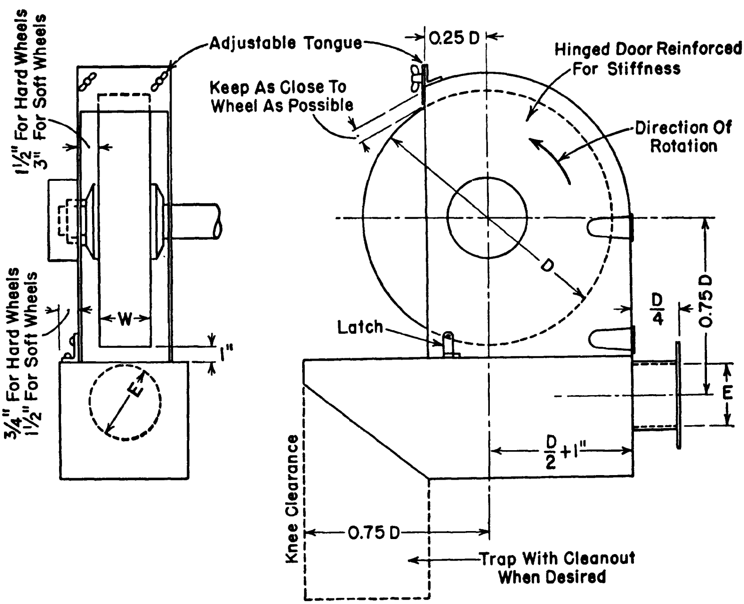


FIGURE 114. Standard Buffing and Polishing Hood (*Courtesy AFA*)

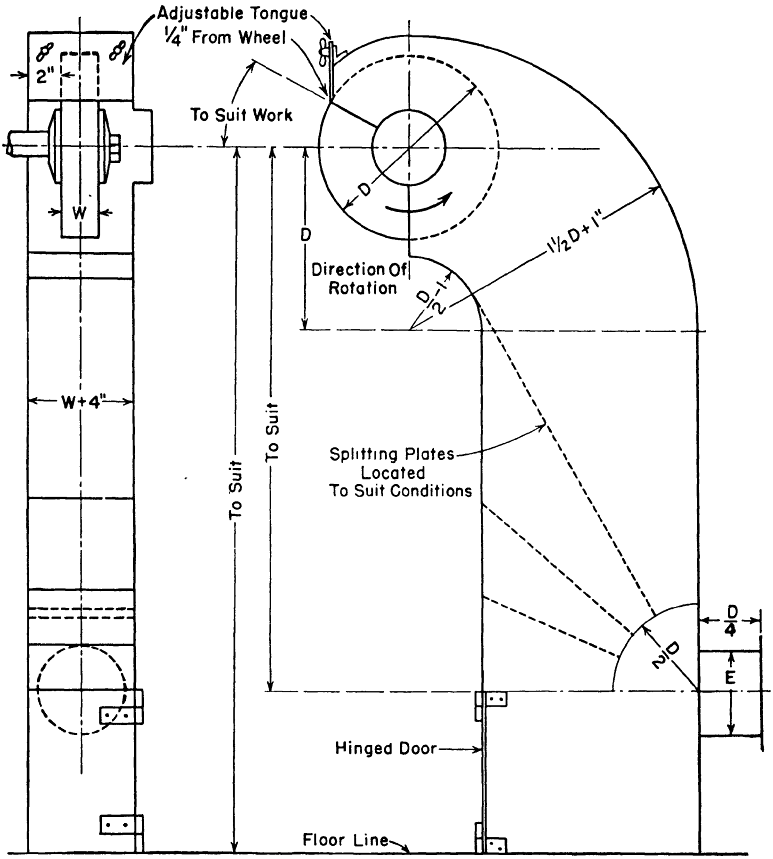


FIGURE 115. Polishing Hood for Large Irregular Parts (*Courtesy AFA*)

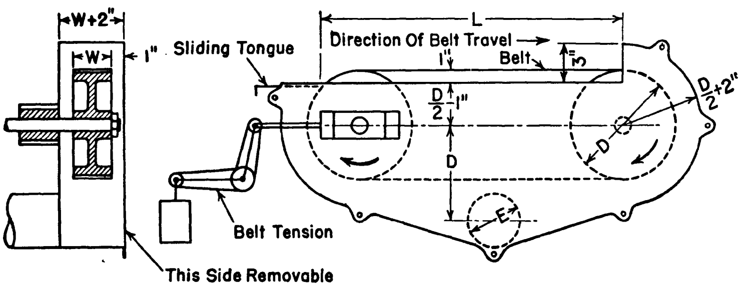


FIGURE 116. Local Exhaust at a Belt for Grinding, Polishing, or Buffing (*Courtesy AFA*)

In figure 117 is shown the design of a typical booth of a very common size. Even though the booth dimensions are given in the figure, this is only by way of illustration and is not intended to

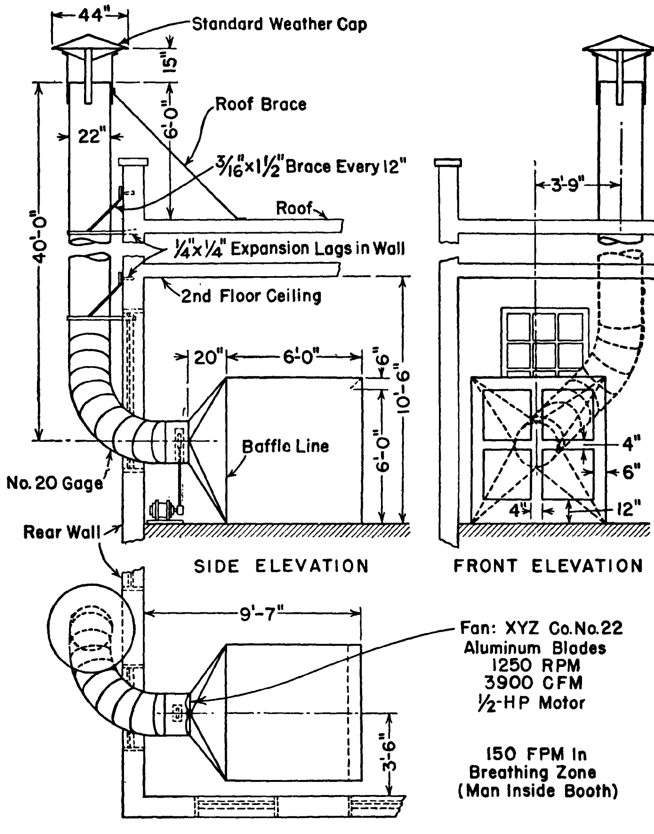


FIGURE 117. Paint-Spray Booth (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

mean that this booth represents *the* standard booth; all sizes to fit the needs are available commercially. Additional specifications applicable to the hood and duct construction shown in figure 117 are as follows:

1. Duct braces to be not more than 12 ft apart.
2. Duct to be riveted, soldered, and lapped in accordance with specifications given in Chapter VI.

3. Bends to have centerline radius of two duct diameters and to be made of seven pieces per 90°.

4. Booth floor and baffles to be of 22-gage steel reinforced with angle iron.

5. Booth to be lighted with vapor proof lamps; switches to be outside.

6. Electric wiring to conform to requirements of National Electric Safety Code.

Additional design data on the booth and on the baffle plates are given in figure 118. Other information pertinent to the figure is

1. Depth of booth to baffle (dimension C in figure)
   a. For pleasure automobile—22 ft.
   b. For truck—length of truck plus 6 ft.

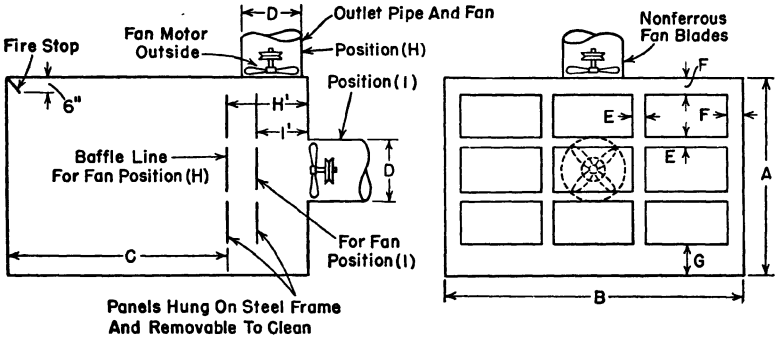


FIGURE 118. Paint-Spray Booth (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

   c. For other work—sufficient to accommodate work and have spray gun held well within the confines of the booth.
2. Location of baffle (dimension H' or I')
   a. H'—fan diameter (D) plus 6 in.
   b. I'—0.75 fan diameter (D).
3. Air-velocity requirements
   a. For highly toxic materials and for small booths (face area not over 4 sq ft)—200 fpm through frontal opening.
   b. Otherwise, 150 fpm through frontal opening.
4. Fan capacity in cubic feet per minute
   a. Frontal opening in square feet (AB) times 200 for small booths (face area not over 4 sq ft) and for highly toxic materials.

b. Otherwise, frontal opening in square feet (*AB*) times 150. (NOTE. If operator stands immediately outside of booth, and if fire stop as shown in figure 118 is provided, 0.5 ft may be subtracted from *A* in *a* and *b* above.)

5. Exhaust duct diameter (*D*)
   Calculated on duct velocity of 2000 fpm.

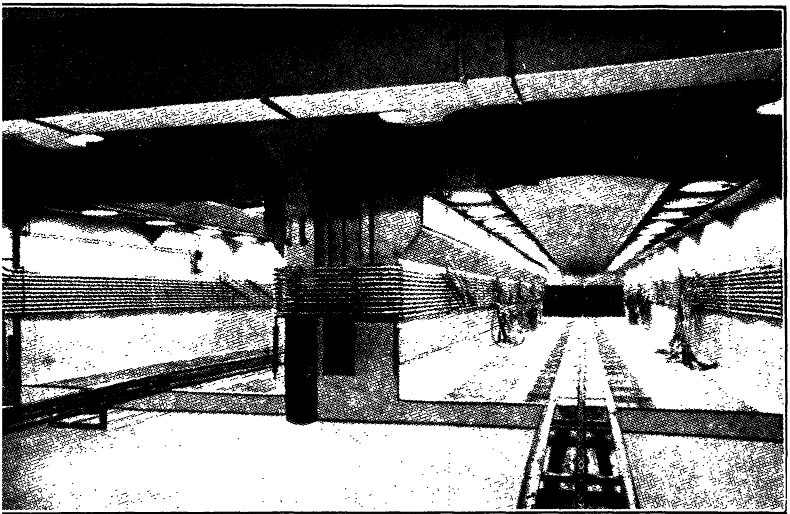


FIGURE 119. Assembly-Line Paint-Spray Booths (*Courtesy National Safety Council*)

6. Fire prevention
   Comply with local ordinances and *NBFU Pamphlet* 33 (Standards of the National Board of Fire Underwriters for Paint Spraying and Spray Booths).

The booth described above is a common one. For special operations such as painting automobiles on an assembly line special construction is needed, and downdraft ventilation at the rate of about 100 cfm per square foot of horizontal cross-sectional area of the booth is needed (see figure 119). Conveyors similar to that shown in figure 120 or of the overhead type are frequently employed to move the parts through the booth for spraying. If the painted parts do not dry before they leave the booth, a drying tunnel as illustrated in figure 120 or a drying room is needed adjacent to the spray booth. Drying enclosures should be exhausted at the mini-

mum rate of 100 cfm per square foot of opening (the access door area to the drying room to be used if substantial permanent openings are not provided).

Stone Cutting. Cutting, grinding, drilling, and surfacing stone produces considerable dust, which is a serious nuisance at best, and constitutes an important health hazard if the stone contains free silica. Probably the best-known industry which has this problem to a large measure and in which much has been done to control the dust is the granite industry.[21, 127, 132, 133, 134] The control measures

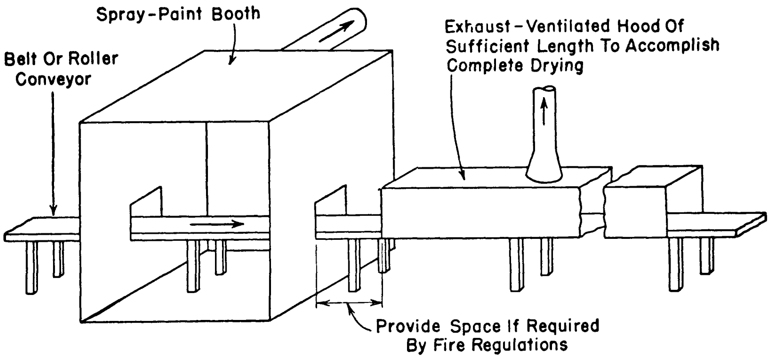


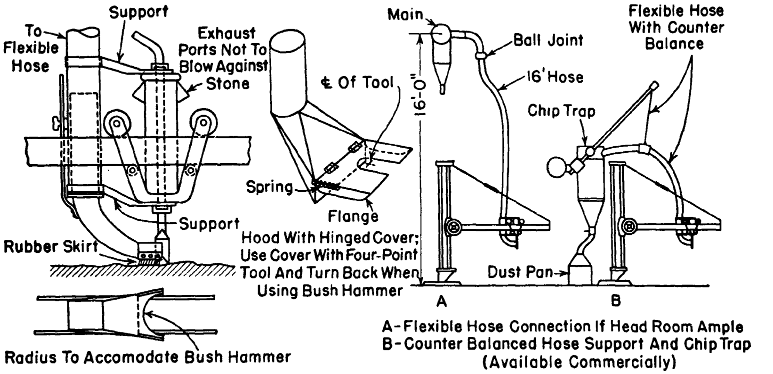
FIGURE 120. Paint-Spray Booth and Drying Tunnel

and equipment are equally applicable to all stone cutting and surfacing operations.

In figure 121 are shown complete design data for local exhaust equipment at a surfacing machine. Similar information for portable grinders is given in figure 122 and for bankers in figure 123. In addition to the information in figure 123, the following specifications are applicable:

1. Volume rate of exhaust ventilation through the hood is 500 cfm at a maximum working distance of 10 in. between the tool and the hood; minimum air velocity at the tool to be 200 fpm.
2. Extra capacity to be allowed for leakage at all telescopic and turning joints.
3. All piping to be of 18-gage material; elbows and containers of 16 gage.
4. Connection from chip trap to main duct to be 45° or less.
5. Chip container to have closed connection to trap.
6. The range of adjustment (dimensions A and B) must be adequate to accommodate all sizes of stone.
7. Adjusting and locking devices to be positive in action and quick acting.

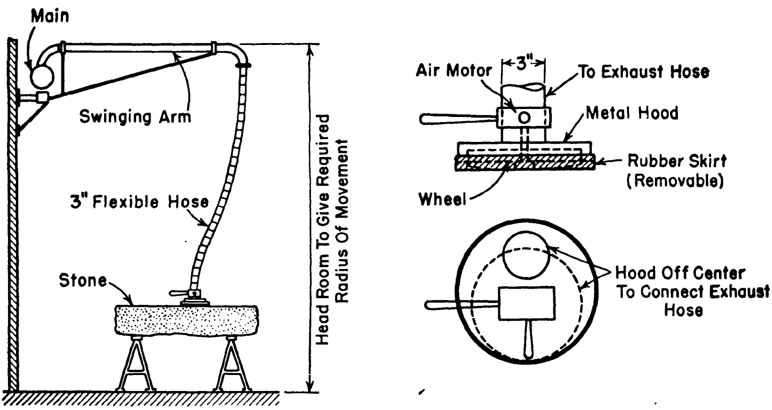
Details of an exhaust ventilated booth for bankers are given in figure 124; additional specifications are



Hood Spec.	Large Surfacer	Small Surfacer
Opening	2½"x 10"	2"x 8"
Hose Diameter	5½"	4"
Air Flow (Min.)	1000 CFM	500 CFM

1. Hood Of No.16-Gage Welded Iron With Renewable Rubber Skirt.
2. Provide Telescopic Joint And Locking Device For Rapid And Positive Hood Adjustment.
3. Design Hood To Give Range Of Adjustment Required By Different Tools.
4. Provide Firm Supports From Hammer To Hood.

FIGURE 121. Exhaust Hood for Surfacing Machine (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)



NOTES
1. Minimum Rate Of Ventilation: 250 CFM.
2. This Method Of Ventilation Adaptable Only On Flat Surfaces.
3. Radius Of Movement Must Be Sufficient To Reach All Parts Of Stone.

FIGURE 122. Exhaust Hood for Portable Grinder (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

1. Air velocity through booth to be 200 fpm; volume rate of exhaust ventilation in cubic feet per minute to be 200*AB* (*A* and *B* in feet).
2. Baffles to be provided as shown.
3. Diameter of discharge stack to be calculated on the basis of a 2000 fpm duct velocity.
4. Height of discharge stack above ground (dimension *E*) to be sufficient to insure dissemination and dilution of dust without excessive recontamination of plant.
5. Weather cap to be dimensioned and constructed in accordance with figure 51.
6. Means to be provided for raising or rolling back roof of booth to permit handling stone by overhead crane.
7. Dimensions *A*, *B*, and *C* to be as required by size of stone and nature of work.

In figure 125 is shown the general layout of exhaust ventilation for pneumatic tools in a typical granite-cutting shop. Additional specifications are

1. Hoods, hose, supporting devices and chip traps for large surfacer and three bankers to be standard equipment.
2. Volume rates of exhaust ventilation to be as given in figure.
3. Minimum duct velocity to be 3300 fpm downstream from chip traps.
4. Ductwork to be of 18-gage or heavier material; joints to be welded or flanged and bolted; duct supports to be not more than 10 ft apart.
5. Bends to have centerline radius of 2 duct diameters.
6. Branch to main-duct connections to be at 45° or less; junction tapers to be at rate of 1 in. per foot.
7. Filter size to be selected on basis of filter velocity of 3 fpm.
8. Fan and motor to be of size adequate to move 3000 (2500 plus allowance for leakage and wear) at the resistance created by the system.
9. Dust and chip collectors to discharge into tight removable containers of 14-gage welded construction.

Tumbling Mills. The sand and dust released from cast parts when they are cleaned by tumbling presents a potentially serious health hazard. To control this hazard tumbling mills are usually provided with local exhaust ventilation.

In *hollow-trunnion*-type tumbling mills as illustrated in figures 126 and 127, the branch duct must of necessity be the same size as the exhaust connection on the mill as provided by the manufacturer. For adequate dust control, the outlet dimensions and the ventilation rate should be as given in table 36. The required duct velocity is about 5000 fpm.

Stave-type tumbling mills as illustrated in figure 128 require enclosure and exhaust ventilation. Inlet openings are provided in the bottom of the front side of the enclosure. The air velocity through

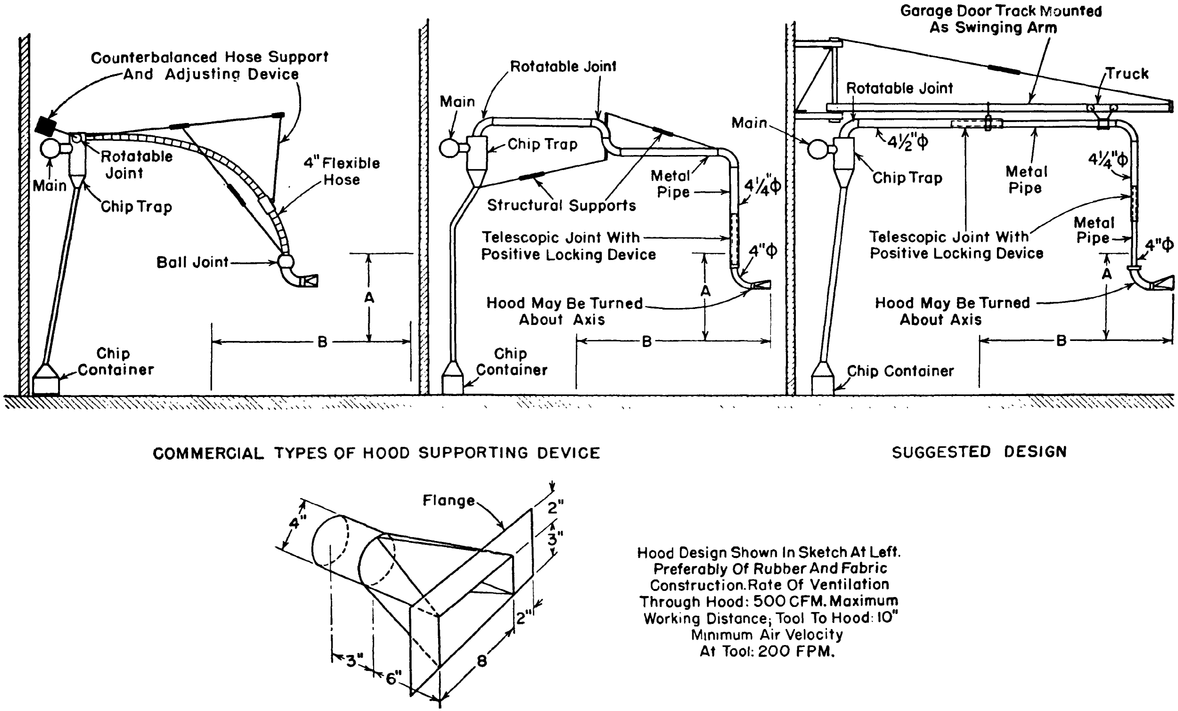


FIGURE 123. Banker Exhaust System—Hood Design, Supporting Device, and Ventilation Requirements (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

these openings should be not less than 400 fpm. The exhaust duct is sized on the basis of a 5000 fpm velocity, and the volume rate of exhaust ventilation for different sizes and shapes of stave-type mills is given in table 36.

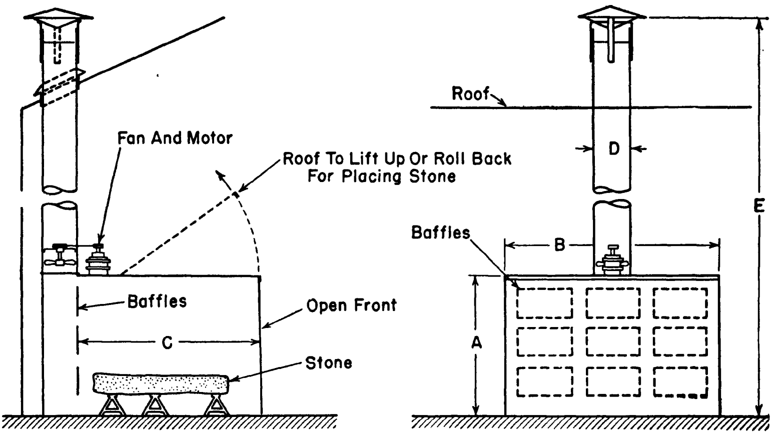


FIGURE 124. Ventilated Exhaust Booth for Banker (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

TABLE 36

RECOMMENDED EXHAUST VENTILATION RATE FOR TUMBLING MILLS
(Duct velocity 5000 fpm)

Round Mill (Inside Diameter in Inches)	Square Mill (Side Dimension in Inches)	*Exhaust Ventilation Rate in Cubic Feet per Minute* Hollow-Trunion Mills *	Stave Mills
24 and less		430	800
24 through 30	24 and less	680	900
30 through 36	24 through 30	980	980
36 through 42	30 through 36	1330	1330
42 through 48	36 through 42	1750	1750
48 through 54	42 through 48	2200	2200
54 through 60	48 through 54	2725	2725
60 through 66	54 through 60	3300	3300
66 through 72	60 through 66	3925	3925
	66 through 72	4600	4600

* For mills longer than 70 in. (inside length), increase the rate of ventilation over the above values in direct proportion to the increase in length.

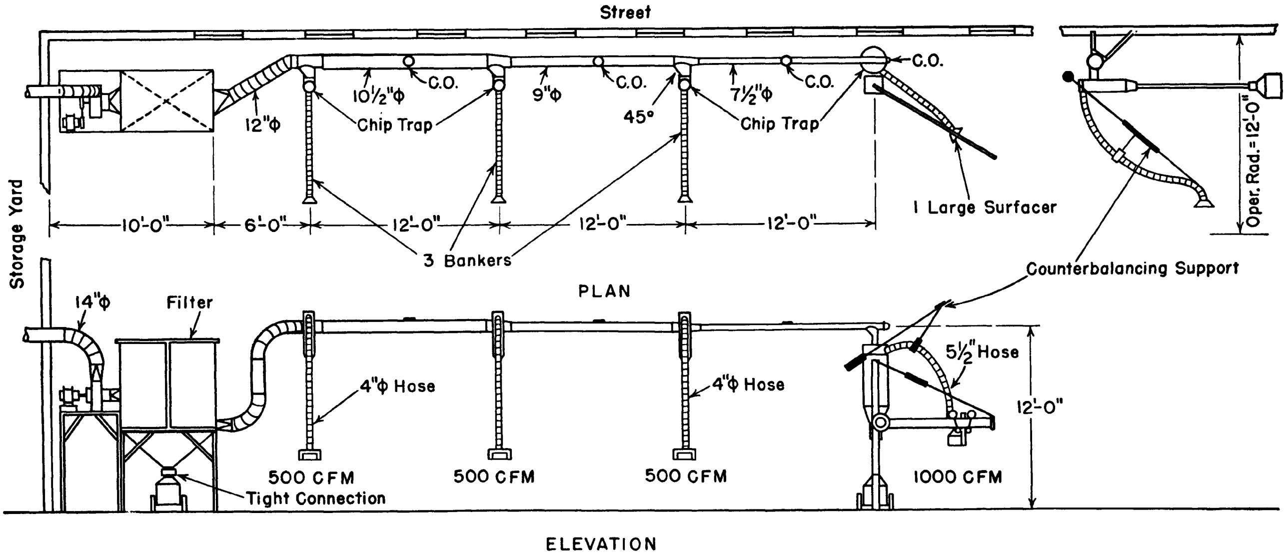


FIGURE 125. Dust Exhaust System Layout for Typical Granite Shed (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

Woodworking. Even though most woodworking machinery produces only a fire and nuisance hazard, it is so common in industry that the engineer needs to have information on the design of dust control for such machinery. Furthermore, many of the shapes and principles demonstrated in local exhaust ventilating systems for woodworking equipment can be applied successfully to other sources of dust or atmospheric contaminant production.

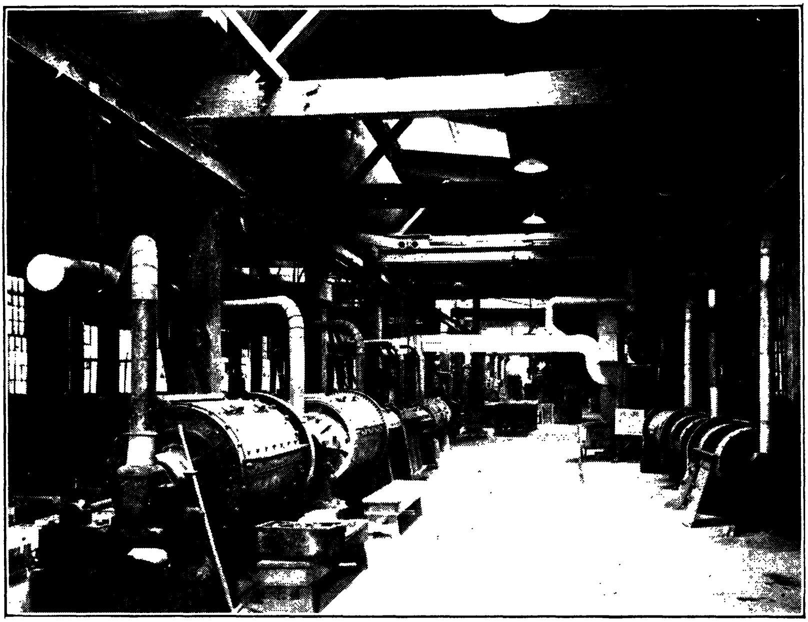


FIGURE 126. Hollow-Trunnion Tumblers with Local Exhaust Ventilation (*Courtesy American Air Filter Co.*)

Local exhaust hoods and connecting ductwork for four different types of saws are shown in figures 129 to 132, for a jointer in figure 133, and for three different types of sanders in figures 134 to 136. A suggested exhaust-ventilating-system layout for a woodworking plant is shown in figure 137. Information on duct sizes for the hoods at most types of woodworking equipment is given in tables 37 and 38. The volume rate of exhaust is computed from the duct size given in the table and also the recommended duct velocity for wood dust of 4000 fpm. Ductwork should be constructed in accordance with the specifications given in Chapter VI.

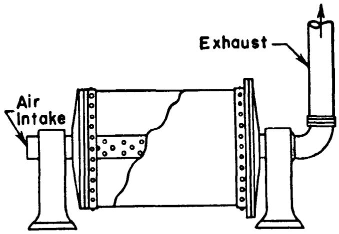


FIGURE 127. Local Exhaust Ventilation at a Hollow-Trunnion Type Tumbler

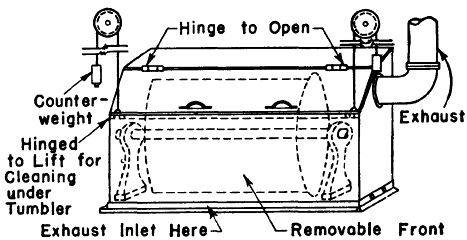


FIGURE 128. Enclosure and Local Exhaust at a Tumbler

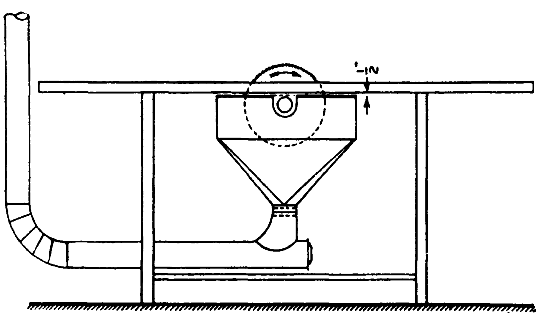


FIGURE 129. Local Exhaust at a Table Saw (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

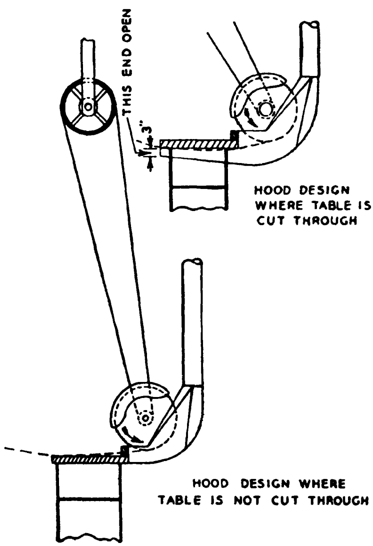


FIGURE 130. Local Exhaust at a Swing Saw (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

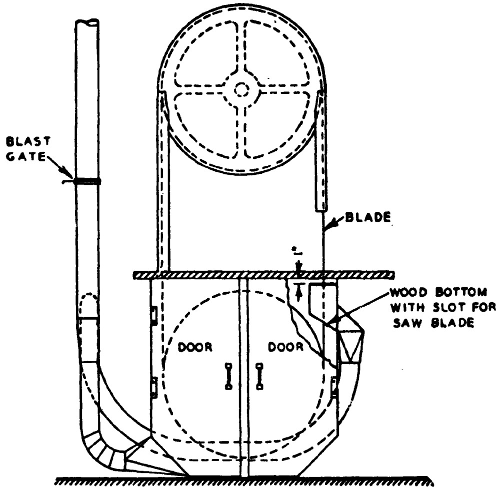


FIGURE 131. Local Exhaust at a Band Saw (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

TABLE 37

DESIGN DATA FOR LOCAL EXHAUST SYSTEMS AT WOODWORKING MACHINES
(Exhaust ventilation rate to be computed on basis of 4000 fpm duct velocity)

Machine or Equipment	Size Indicated by	Size	Branch Ducts		
			Designation	Number	Diameter (inches)
Jointers	Knife length	6 in. and less		1	4
		6 in. through 12 in.		1	4½
		12 in. through 20 in.		1	5
		over 20 in.		1	6
Molders, matchers, and sizers	Knife length	7 in. and less	Right head	1	4
		7 in. and less	Left head	1	4
		7 in. and less	Bottom head	1	4½
		7 in. and less	Top head	1	5
		7 in. through 12 in.	Right head	1	4½
		7 in. through 12 in.	Left head	1	4½
		7 in. through 12 in.	Bottom head	1	5
		7 in. through 12 in.	Top head	1	6
		12 in. through 18 in.	Right head	1	5
		12 in. through 18 in.	Left head	1	5
		12 in. through 18 in.	Bottom head	1	6
		12 in. through 18 in.	Top head	1	7
		18 in. through 24 in.	Right head	1	6
		18 in. through 24 in.	Left head	1	6
		18 in. through 24 in.	Bottom head	1	7
		18 in. through 24 in.	Top head	1	8
		over 24 in.	Right head	1	7
		over 24 in.	Left head	1	7
		over 24 in.	Bottom head	1	8
		over 24 in.	Top head	1	9
Planers					
Double planers	Knife length	20 in. and less	Top branch	1	5
		20 in. through 26 in.	Top branch	1	6
		26 in. and less	Bottom branch	1	5
		26 in. through 36 in.	Top branch	1	7
		26 in. through 36 in.	Bottom branch	1	6
		over 36 in.	Top branch	1	8
		over 36 in.	Bottom branch	1	7
Single planers	Knife length	20 in. and less		1	5
		20 in. through 26 in.		1	6
		26 in. through 36 in.		1	7
		over 36 in.		1	8
Sanders					
Disc sander	Disc diameter	12 in. and less		1	4
		12 in. through 18 in.		1	4½
		18 in. through 26 in.		1	5
		26 in. through 32 in.		2	4
		32 in. through 38 in.		1	4
				1	5
		38 in. through 48 in.		2	4
				1	5

TABLE 37 (*Continued*)

DESIGN DATA FOR LOCAL EXHAUST SYSTEMS AT WOODWORKING MACHINES
(Exhaust ventilation rate to be computed on basis of 4000 fpm duct velocity)

Machine or Equipment	Size Indicated by	Size	Branch Ducts		
			Designation	Number	Diameter (inches)
Sanders (Cont.)					
Single drum sander	Drum diameter	10 in. and less		1	4
		over 10 in.		1	4½
	Surface area	400 through 700 sq in.		1	5
		700 through 1400 sq in.		1	6
		1400 through 2400 sq in.		1	7
	Working space	200 sq in. maximum		1	4
		400 sq in. maximum		1	4½
Triple drum sander	Drum length	30 in. and less		1	7
		30 in. through 36 in.		1	8
		36 in. through 42 in.		1	9
		42 in. through 48 in.		1	10
		over 48 in.		1	11
Horizontal belt sander (bottom run)	Belt width	6 in. and less	Bottom branch	1	4½
		6 in. through 9 in.	Bottom branch	1	5
		9 in. and less	Top branch	1	4
		9 in. through 14 in.	Top branch	1	4½
		9 in. through 14 in.	Bottom branch	1	6
		over 14 in.	Top branch	1	5
		over 14 in.	Bottom branch	1	7
Horizontal belt sander (top run, *flat work*)	Belt width	6 in. and less	(Bottom branch only required)	1	4½
		6 in. through 9 in.		1	5
		9 in. through 14 in.		1	6
		over 14 in.		1	7
(*other work*)		9 in. and less	(Hood and telescope joint)	1	4
		9 in. through 14 in.		1	4½
		over 14 in.		1	5
Vertical belt sander	Belt width	6 in. and less		1	4½
		6 in. through 9 in.		1	5
		9 in. through 14 in.		1	6
		over 14 in.		1	7
Swing arm sander				1	4
Saws					
Self-feed table rip	Saw diameter	16 in. and less	Bottom branch	1	4½
		over 16 in.	Bottom branch	1	5
		all sizes	Top branch	1	4
Swing saw	Saw diameter	20 in. and less		1	4
		over 20 in.		1	4½
Rip, table, mitre, and variety saws	Saw diameter	16 in. and less		1	4
		16 in. through 24 in.		1	4½
		over 24 in.		1	5

TABLE 37 (*Continued*)

DESIGN DATA FOR LOCAL EXHAUST SYSTEMS AT WOODWORKING MACHINES
(Exhaust ventilation rate to be computed on basis of 4000 fpm duct velocity)

Machine or Equipment	Size Indicated by	Size	Branch Ducts		
			Designation	Number	Diameter (inches)
Saws (Cont.)					
Vareity saw with dado head	Saw diameter		One branch	1	5
Gang rip saw	Saw diameter	24 in. and less	Top branch	1	4
		24 in. and less	Bottom branch	1	5
		24 in. through 36 in.	Top branch	1	4½
		24 in. through 36 in.	Bottom branch	1	6
		36 in. through 48 in.	Top branch	1	5
		36 in. through 48 in.	Bottom branch	1	7
		over 48 in.	Top branch	1	5½
		over 48 in.	Bottom branch	1	8
Band saw	Blade width	2 in. maximum	(see figure 131)	2	4
Band resaw	Blade width	3 in. and less	Up run	1	4
		3 in. and less	Down run	1	5
		3 in. through 8 in.	Up run	1	5
		3 in. through 4 in.	Down run	1	6
		4 in. through 6 in.	Down run	1	7
		6 in. through 8 in.	Down run	1	8

Other hood shapes for woodworking equipment are shown in Figure IV of the Appendix.

Installation Examples. It is axiomatic that one profits by examples. Consequently, the remainder of this chapter will be devoted to illustrations and brief discussions of several local exhaust ventilating systems which were either unusual in design or particularly satisfactory in operation.

In figures 138 and 139 are shown before and after photographs of conditions at an electric furnace. If the dust and smoke is permitted to escape from the furnace it requires a large exhaust ventilation rate to capture it satisfactorily. Since the furnace top raises and swings out of position, the usual stationary type of hood could not be used. A hood of special construction solved the problem by being attached to the furnace top as an integral part. When in position the hood makes a fairly tight joint with the stationary exhaust duct. The required exhaust ventilation rate is only 15 to

TABLE 38

DESIGN DATA FOR LOCAL EXHAUST SYSTEMS AT MISCELLANEOUS WOODWORKING EQUIPMENT

(Exhaust ventilation rate to be computed on basis of 4000 fpm duct velocity)

Operation	*Hoods and Branch Ducts*
Tenoner	Top head 5-in. branch; bottom head 5-in. branch; other heads 4½-in. to 5-in. branches. Use 4-in. branches where saws are used
Woodshapers and variety machines	4½-in. to 6-in. branch for each spindle
Chain mortises	3-in. branch
Dovetail, lock corner, and dowell machines; duplex molding sanders; forming lathes; panel raisers (each head); ploughs; rail shears; routers; and sash stickers (each head)	4-in. branch
Pulley pockets and pulley stiles	5-in. branch
Glue jointer	6-in. branch
Hogs	8-in. branch up to 12-in. width; 12-in. branch for widths over 12 in.
Floor sweeps	6-in. branch for fine dust; 8-in. branch for coarse. Hood at floor from 10 in. x 4 in. to 12 in. x 5 in. (Exhaust volume rate for floor sweeps need not be included in computing total volume requirements)

30% of that required with other types of hoods. The effectiveness of the hood is demonstrated in the figures.

In figure 140 is shown a radium-dial-painting hood with a transparent top permitting the operator to see his work, which is conducted within the hood. The face velocity at the hood is 200 fpm, which is probably higher than necessary (see Chapter X). Since the work done at this hood requires blowing out the assembled instruments with compressed air, the metal funnel at the left of each hood is provided for this purpose. The face velocity at the funnel is about 900 fpm.

In figures 141 and 142 are shown local exhaust hoods at annealing furnaces. Figure 142 shows the conditions at a furnace when the processed parts are being discharged and with the exhauster not operating. Previous to installation of the local exhaust system at these furnaces, the operators could not stay in the room while the annealed parts were being dumped owing to the irritation of the acrolein and other irritating gases liberated by the processed parts.

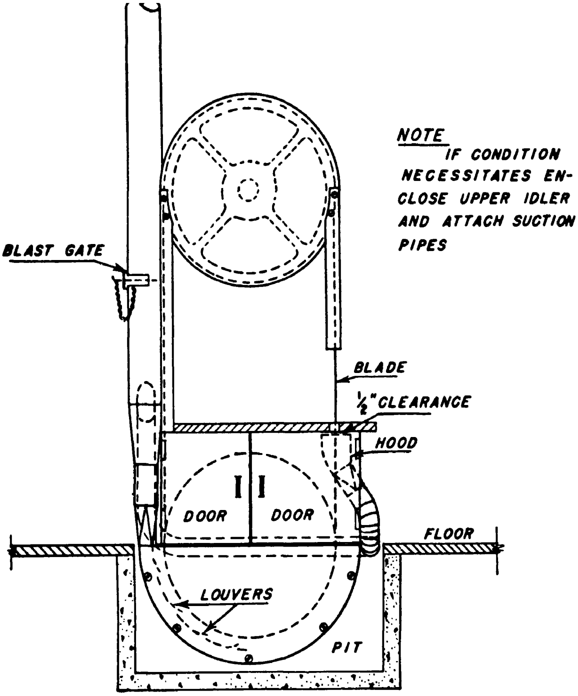


FIGURE 132. Local Exhaust Hoods at a Band Resaw Machine (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

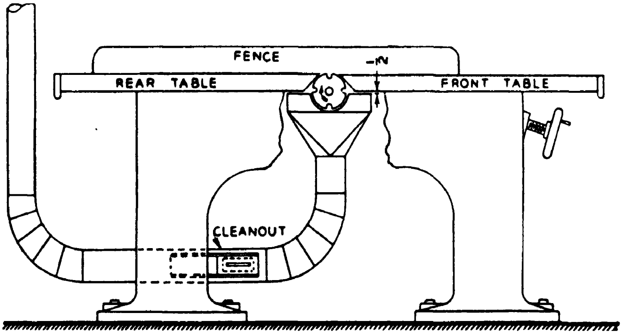


FIGURE 133. Local Exhaust at a Jointer (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

The effectiveness of the hood during dumping operations is shown in figure 141.

Effective control of the irritating smoke and gases liberated at a production brazing operation using a fluoride flux is shown in figure

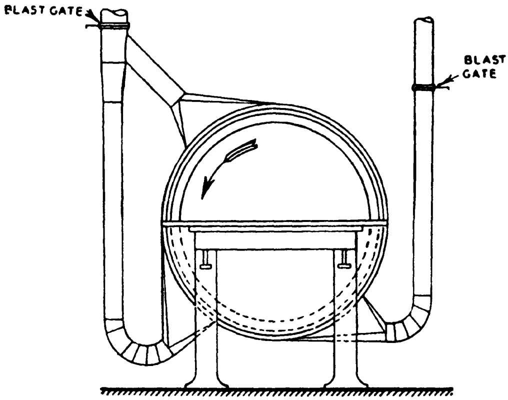


FIGURE 134. Local Exhaust at a Disc Sander (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

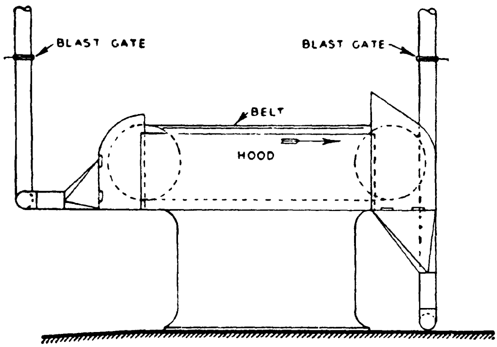


FIGURE 135. Local Exhaust at a Belt Sander (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

143. The parts to be brazed are placed on the rotating wheel by the operator at the rear, making the brazing operation a continuous one.

An example of a difficult control job is shown in figures 144 and 145. The exhaust hood encircles the grinder spindle. Since a relatively large volume of air must be exhausted through the small

opening into the hood, a high-suction low-volume exhauster, such as an industrial vacuum cleaner, is needed for this operation. The dust produced by the grinder when not controlled is shown in figure 145, the exhauster having been shut off for this photograph.

The conventional type of exhaust hood for asbestos carding ma-

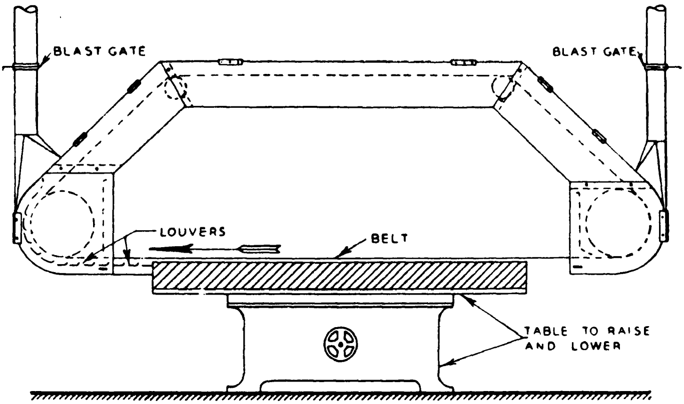
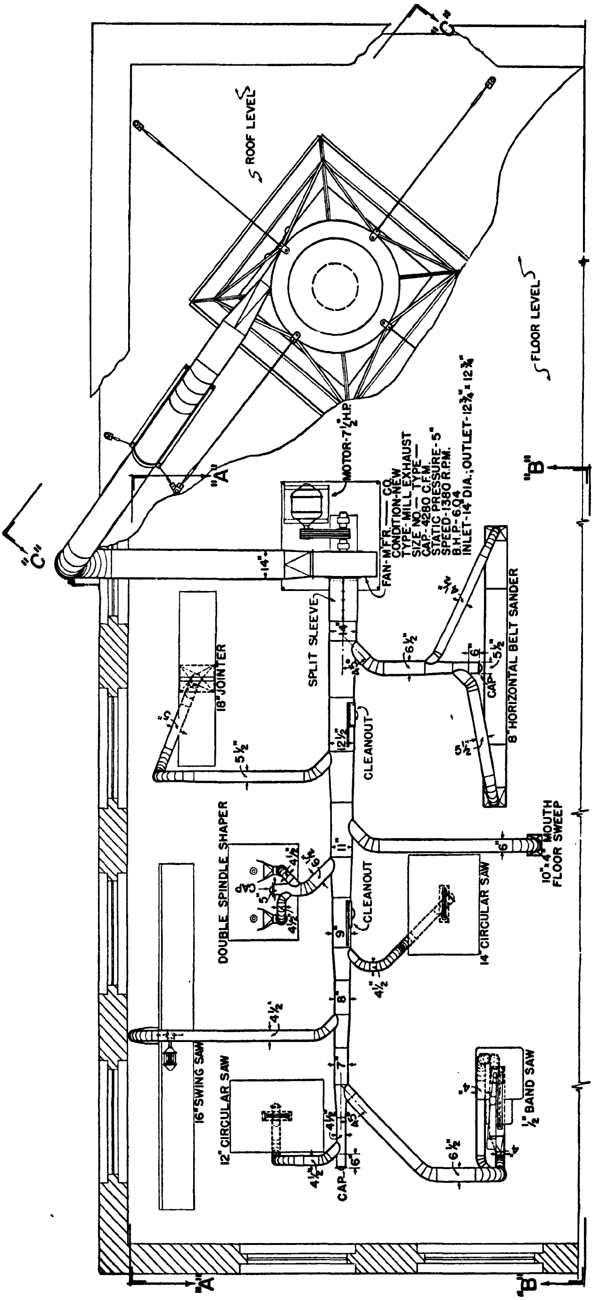


FIGURE 136. Local Exhaust at a Belt Sander (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

chines is illustrated in figure 146. In the figure, the hood is swung up to show the asbestos fibers being thrown from the machine. With the hood lowered and in operating position, considerable quantities of asbestos are removed from the machines by this type of exhaust hood. An improved hood is shown in figure 147. The top of the carding machine is covered completely, and exhaust is accomplished only through the outlets located near the sides of the machine. With this arrangement, only those fibers which would normally be thrown into the working area at the sides of the machine are drawn into the local exhaust system. The result is an effective control installation with lower rates of asbestos removal by the exhaust system. Draw bands are employed on all duct connections leading to the hood so that it may be removed readily for machine maintenance and repair.

In figure 148 is shown the dust control enclosure at the feed bin ahead of the carding machine. By covering the feed bin entirely and providing local exhaust ventilation, the large amount of dust normally dispersed at this location is eliminated.


ROOF LEVEL
FLOOR LEVEL
MOTOR-7½ H.P.
FAN-MFR.—— CO.
CONDITION-NEW
TYPE-MILL EXHAUST
SIZE NO.— TYPE—
CAP.-4280 C.F.M.
STATIC PRESSURE-5"
SPEED-1380 R.P.M.
B.H.P.-6.04
INLET-14" DIA.; OUTLET-12¾"×12⅜"
SPLIT SLEEVE
CLEANOUT
CLEANOUT
18" JOINTER
8" HORIZONTAL BELT SANDER
DOUBLE SPINDLE SHAPER
10"×4" MOUTH FLOOR SWEEP
14" CIRCULAR SAW
16" SWING SAW
12" CIRCULAR SAW
½" BAND SAW
CAP
CAP
"A"
"B"
"C"

PLAN

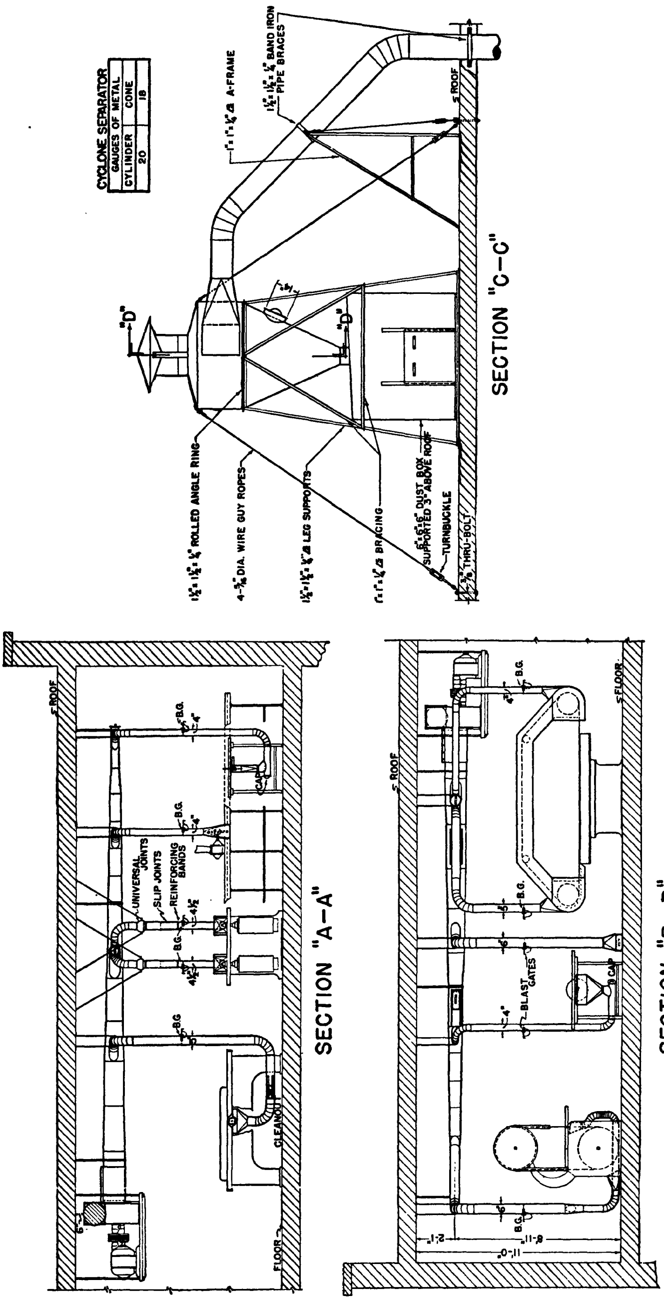


FIGURE 137. Exhaust-System Layout for Typical Woodworking Plant (*Courtesy N. Y. Labor Department, Division Industrial Hygiene and Safety Standards*)

FIGURE 138. Electric Furnace without Hood (See Also Figure 139) (*Courtesy American Air Filter Co.*)

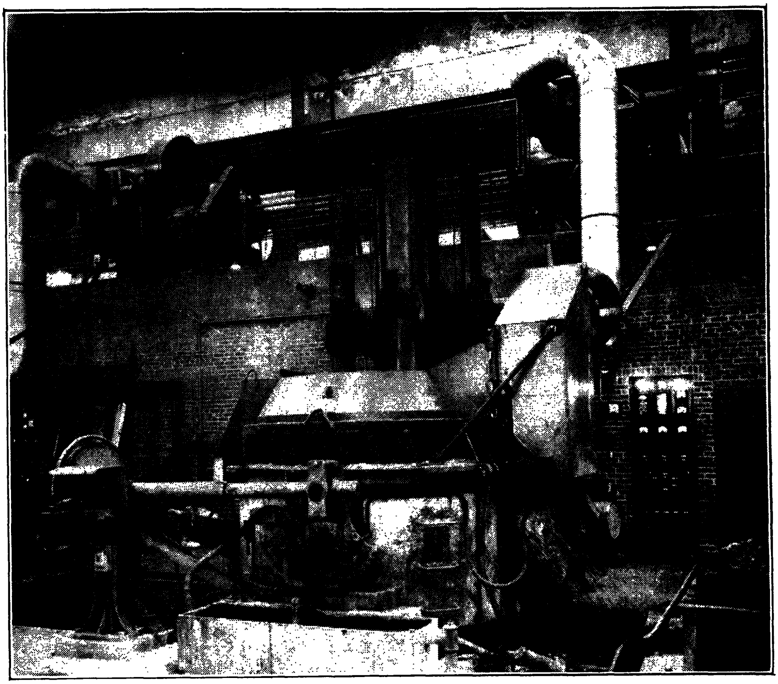


FIGURE 139. Local Hood on Furnace Shown in Figure 138 (*Courtesy American Air Filter Co.*)

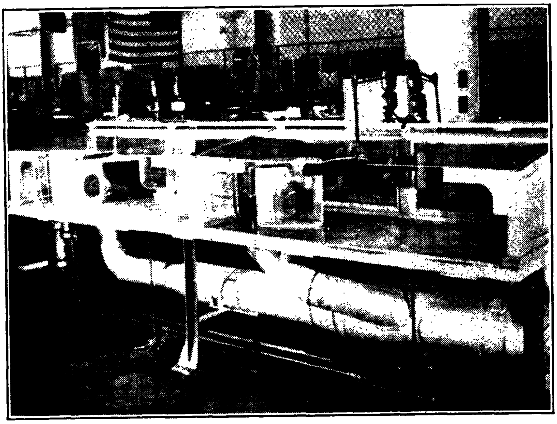


FIGURE 140. Enclosing Hood for Luminous-Dial Painting (*Courtesy Connecticut Department of Health*)

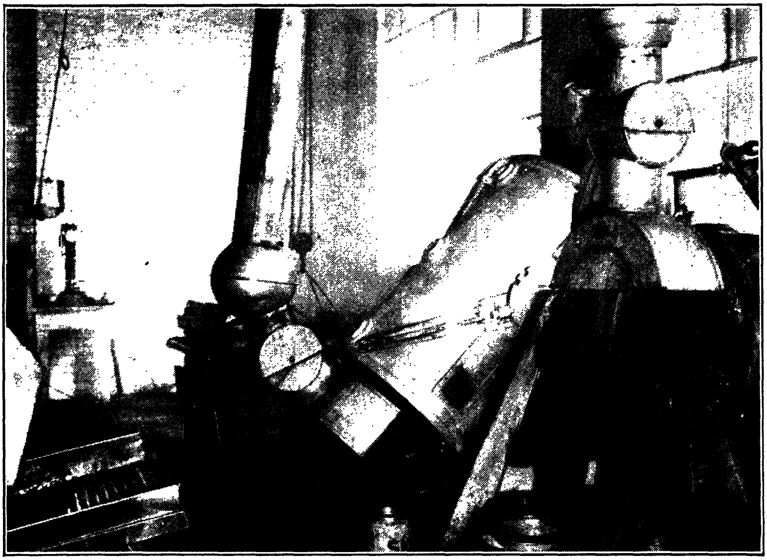


FIGURE 141. Local Exhaust Ventilation at an Annealing Furnace—Fan On (*Courtesy Connecticut Department of Health*)

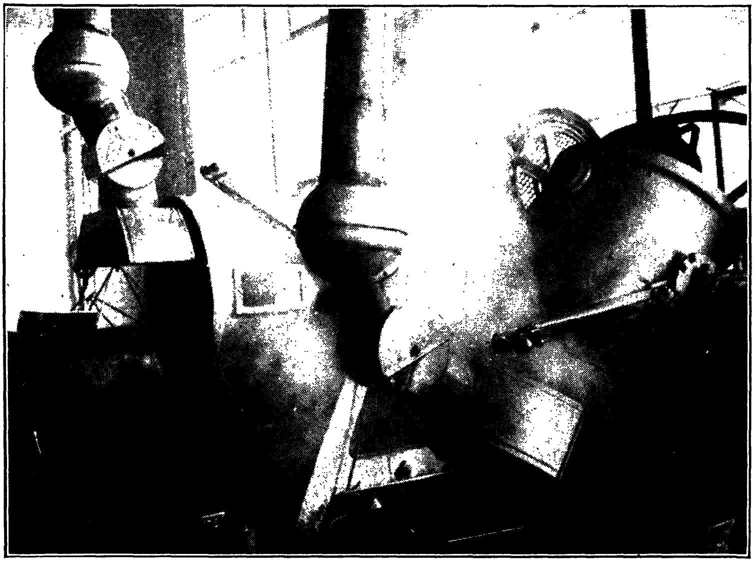


FIGURE 142. Local Exhaust Hood at Annealing Furnace—Fan Off (*Courtesy Connecticut Department of Health*)

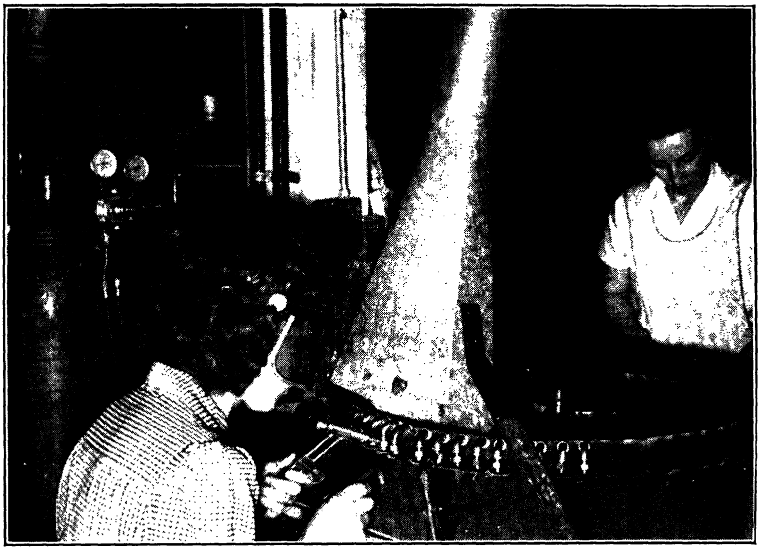


FIGURE 143. Local Exhaust Hood at a Production Brazing Operation (*Courtesy Connecticut Department of Health*)

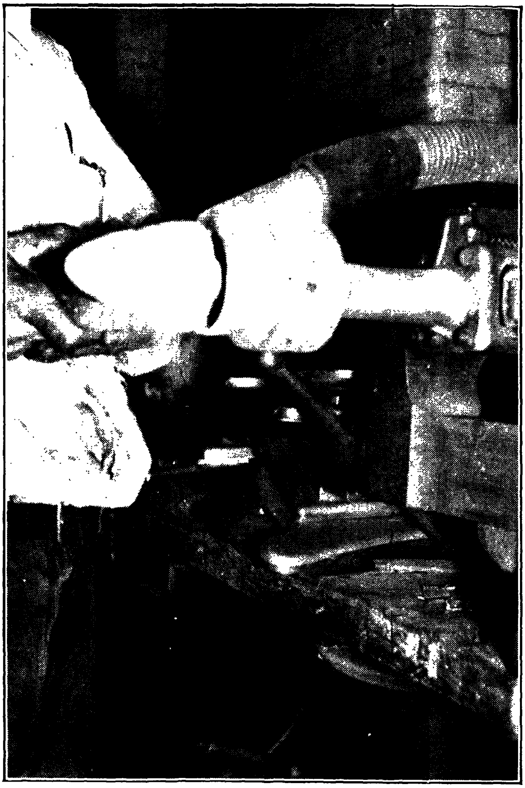


FIGURE 144. Local Exhaust Ventilation at a Small Grinder—Suction On (*Courtesy Connecticut Department of Health*)

FIGURE 145. Local Exhaust Hood at a Small Grinder—Suction Off (*Courtesy Connecticut Department of Health*)

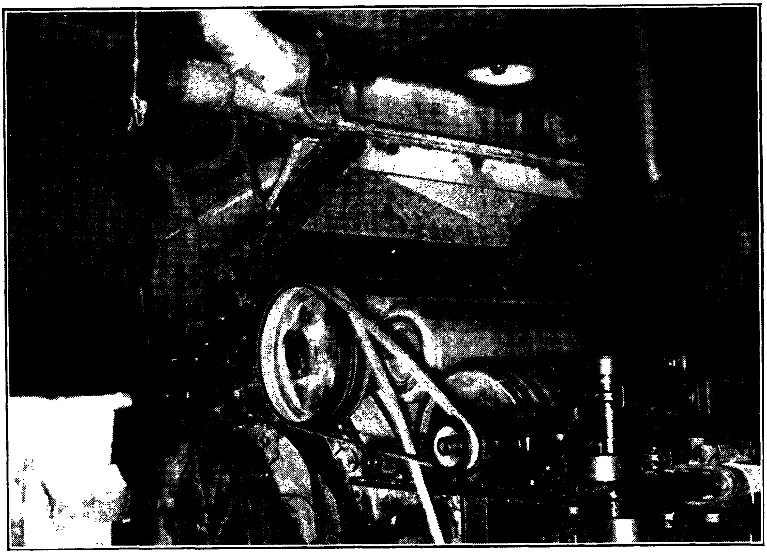


FIGURE 146. Local Exhaust Hood at a Carding Machine (*Courtesy Connecticut Department of Health*)

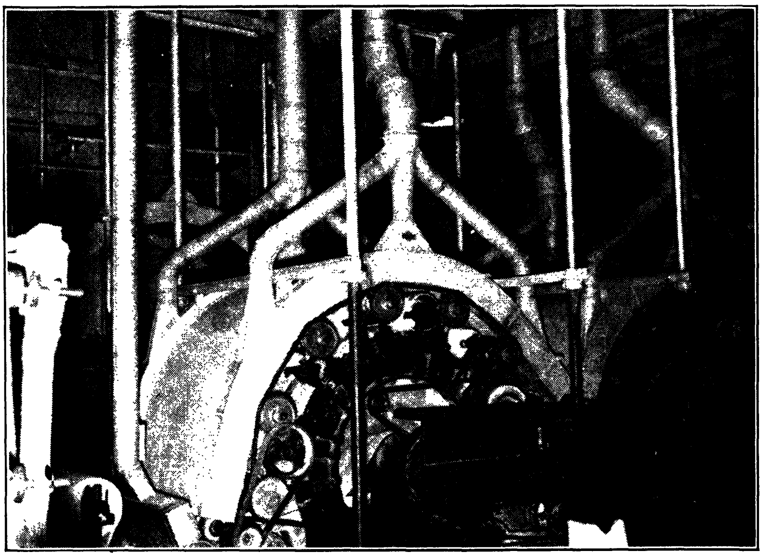


FIGURE 147. Improved Hood at a Carding Machine (*Courtesy Connecticut Department of Health*)

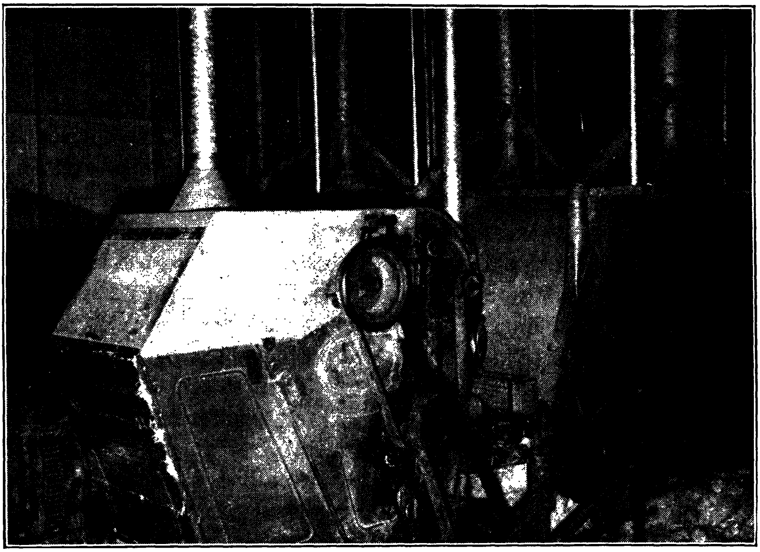


FIGURE 148. Dust Control at a Feed Bin for a Carding Machine (*Courtesy Connecticut Department of Health*)

CHAPTER XII

RESPIRATORS AND PROTECTIVE CLOTHING

The term "respirators" or "respiratory protective devices" as used throughout this chapter is intended to cover all such devices including gas masks, oxygen-breathing apparatuses, chemical-cartridge respirators, hose masks, abrasive-blasting respirators, air-line respirators, and mechanical-filter respirators. Such devices, as indicated in Chapter III, do not accomplish industrial atmospheric sanitation, they merely provide the wearer with safer air than exists in his immediate surroundings.

Respiratory protective devices are probably the oldest method of controlling occupational diseases. Their first use dates back at least as far as the Christian era. Filter respirators of a sort, for use against vermilion dust, were described by Pliny the Elder (23–79 A.D.),[135] and Agricola in his *Re De Metallica*[136] mentions the use of such devices in various mining operations in the sixteenth century. The real development of these devices, however, dates from the first world war.

In the control of occupational diseases caused by breathing air contaminated with harmful dusts, fumes, mists, gases, or vapors, primary consideration should always be given to preventing the air from becoming contaminated. This is accomplished insofar as possible by the methods discussed in Chapters III to VI inclusive. However, regardless of the best efforts in this direction, there will always be many places where potential exposure to harmful concentrations of atmospheric contaminants will exist. Some of these will be emergency situations or accidents due to failure of equipment or error in operating procedure; others will be more or less routine working conditions to which other engineering control procedures are not applicable, not adequately effective, or too costly.

Personal respiratory protective devices are designed to meet these conditions. They are intended to serve as adjuncts to other control measures, not as substitutes for them. Dependable respiratory protection equipment that meets the needs of any situation is avail-

able commercially, and may be had on short notice and at a relatively low cost. However, for this very reason, such equipment is frequently misused and abused. To know where and where not, when and when not, to use respirators and how to select and use such equipment properly, it is necessary to be acquainted with the various types of respirators, their uses, and limitations. It is the aim of this chapter to give the industrial hygiene engineer sufficient information on this subject to enable him to know where and how respirators should be used.

TYPES OF RESPIRATORS

All respiratory protective devices may be divided into two broad groups by nature of operation; these groups may then be further subdivided as will be shown later. One group (supplied-air respirators) protects the wearer from the harmful surrounding atmosphere by supplying him with respirable air from a source of supply which is independent of his working environment. These devices function on two different principles. Some (oxygen-breathing apparatuses) are self-contained and make the wearer independent of any other source of air. The others in this group function by providing a means for conveying respirable air from an outside source to the wearer. The second group comprises air-purifying respirators. Protection is provided the wearer of such devices by filtering some or most of the contaminant from the air as it is inhaled.

Respiratory protective devices may be needed for (1) emergency or (2) nonemergency situations. Emergency situations are those involving actual or potential exposure to atmospheres which are immediately harmful and dangerous to health or life after comparatively short exposures (acute poisoning). Nonemergency situations are the normal or routine situations involving exposure to atmospheric conditions not immediately dangerous to health or life but which will produce marked discomfort, chronic sickness, permanent harm, or death after prolonged or repeated exposure. Some respirators have been designed, and are intended, to meet emergency needs, some to meet only nonemergency needs, and some to meet both. The primary requisite of devices for emergency situations is complete respiratory protection with safety provisions against even momentary failure of the devices which would expose the wearer to the atmosphere and place his life in jeopardy. The important requisites for nonemergency respirators are adequate protection,

minimum inconvenience, and simplicity in design, operation, and use.

Supplied-Air Respirators. Included in this group of protective devices are oxygen- and air-breathing apparatuses, hose masks, air-line respirators, and abrasive-blasting, metal- and paint-spraying hoods and helmets. As indicated previously, this group of respirators operates on the principle of separating the wearer from his immediate atmosphere, as regards the air he breathes, and providing him with respirable air from another source, from containers carried by the wearer in the case of self-contained breathing apparatuses, and from some remote source for the other types of supplied-air respirators.

Self-contained apparatuses most common in industry are oxygen-breathing apparatuses in which the source of oxygen is contained under pressure in cylinders carried by the wearer who breathes the oxygen in a closed circuit. The carbon dioxide is removed from the system by a chemical sorbent contained in the circuit. Recently a similar device has been placed on the market in which compressed air replaces the compressed oxygen. Also, since the close of the second world war, an oxygen-generating canister-type device has been made available. It is relatively simple to use and eliminates many of the disadvantages or objections to the use of respirators of this kind. All of these devices separate the wearer entirely from his external environment as regards the air he breathes and are independent of any outside connections.

The self-contained breathing apparatuses are essentially emergency devices. They require special and adequate training of the wearer since they are relatively complex in operation. These devices give protection from gases, vapors, dusts, fumes, smokes, and mists in any concentration that the skin can endure and from any atmosphere deficient in or devoid of oxygen. It is the only type of equipment that provides this degree of protection and also permits complete freedom of travel of the wearer for considerable distances from respirable air. Some examples of use are rescue and recovery work following mine explosions; fighting fires in mines, tunnels, buildings and ships; entering unventilated tanks that contain volatile liquids such as petroleum and gasoline; in sewers and caves; in unventilated holds, compartments, ballast tanks, and bottom spaces of ships; and all emergency situations in industry. Even though self-contained apparatuses protect against high concentrations of contaminants and against oxygen deficiencies it must be borne firmly in mind that they

do not protect the wearer against some few gases such as hydrogen cyanide which may be absorbed through the skin in harmful amounts.

Hose masks are of two types: those with blowers for supplying the respirable air to the mask under a slight pressure, and those without blowers in which the air is drawn through the hose by the respiratory action of the wearer. The more common hose mask with blower consists of a tight-fitting, full-mask facepiece, a noncollapsible, large-diameter hose line, a hand-operated (or mechanically operated) blower, and a sturdy harness which provides a means for anchoring the end of the hose line to the wearer and serves as a belt for attaching a life line for rescuing him if in trouble. The hose diameter is large, and the blower construction is such as to permit the wearer to inhale air without difficulty even if the blower is not operating.

Hose masks with hand-operated blowers are essentially emergency devices. They give complete protection from all dusts, fumes, mists, smokes, gases, and vapors and are the simplest and safest respirator for use in very dangerous situations where the wearer need not go more than 150 ft (maximum hose length approved by the Bureau of Mines) from respirable air. It is the only hose-type supplied-air respirator approved by the Bureau of Mines for protection from immediately harmful atmospheres. Even though these devices are heavy and cumbersome as compared to air-line respirators they are used in place of such respirators on nonemergency jobs where a supply of respirable air under pressure is not available.

Emergency-type uses of hose masks with blowers are the same as for self-contained apparatuses given previously. Examples of nonemergency uses are protection against the contamination that frequently lingers after cleaning and ventilating tanks and vessels and welding and cutting operations in confined spaces, and if equipped with a suitable hood a hose mask with blower will give good protection for abrasive blasting and metal or paint spraying.

The *special type,* or *hose mask without blower,* is similar in many respects to the one with blower, the essential differences being the absence of the blower and the shorter hose length. It is essentially a simple air conduit leading from a zone of fresh air to the facepiece on the wearer through which he inhales. The facepiece may be either the full-mask or half-mask type, the full-mask type being the more common. The maximum hose length permitted on devices of this kind approved by the Bureau of Mines is 25 ft.

The hose mask without blower gives protection from the inhalation of any form or kind of atmospheric contaminant. It is essentially a

nonemergency device, its field of use being similar to that of gas masks, air-line respirators, chemical-cartridge respirators, and mechanical-filter respirators which are discussed later. Because no source of air under pressure is needed, hose masks without blowers are excellent substitutes for air-line respirators on many jobs where the work is done within 25 ft of a source of uncontaminated air.

In *air-line respirators,* the air breathed by the wearer is supplied to him from a source of uncontaminated air under pressure through a small diameter high-pressure hose line. The facepiece may be tight- or loose-fitting, or it may even be a hood or helmet enclosing the wearer's entire head. The more common types have snugly fitting half-mask-type facepieces. The source of air may be a low pressure or semicompressor or the usual compressor. If internally lubricated compressors are used, precautions must be taken against overheating lest the oil be decomposed with the formation of carbon monoxide. There are available commercially today low-pressure units which do not present this serious, potential health hazard.

The field of use of air-line respirators is very similar to that of mechanical-filter respirators, chemical-cartridge respirators, gas masks, which will be discussed later, and hose masks without blowers, covered previously. Air-line respirators provide good protection from all dusts, fumes, mists, smokes, gases, and vapors. These respirators are essentially nonemergency devices, and are not safe for use in emergency situations from which the wearer could not escape without respiratory protection. The most serious danger in using air-line respirators in emergency situations is the possibility of failure of the air supply, which would immediately jeopardize the wearer's life. This same condition cannot arise with hose masks as pointed out earlier since the hose line is large enough in diameter to permit the wearer to inhale through it.

Air-line hoods are very similar to air-line respirators except that the usual mask is replaced by a thin, light-weight hood that encloses the entire head of the wearer. The quantity of air supplied to the hood is sufficient for the wearer, and to maintain a continuous outflow of air, thereby preventing inflow of contaminated air. The hoods are simple in design and in some models are made of cheap material that can be thrown away when they become soiled. These hoods are nonemergency devices and have a field of use similar to that of air-line respirators, chemical-cartridge respirators, and mechanical-filter respirators. They are particularly well adapted for spray painting of auto bodies and similar operations where protection is needed for

the exposed surfaces of the worker in addition to respiratory protection.

Abrasive-blasting and metal-spraying respirators (sandblast helmets, hoods, and masks) are essentially air-line respirators (or hose masks) with the addition or substitution (for the mask) of a head covering to protect the wearer's head, neck, and shoulders from abrasion by the rebounding particles of abrasive. Some devices are fundamentally air-line hoods while others are fundamentally air-line respirators, the difference being that in the first type there is no facepiece as the head covering or hood serves to bring the supplied air to the wearer's nose; while in the second type the supplied air is delivered to the wearer's nose through a full- or half-mask facepiece, and the helmet or hood serves merely to protect the head, neck, and shoulders. As a rule, more air is needed for adequate protection if delivered to the nose of the wearer through a hood than if delivered through a facepiece.

Properly constructed equipment of this kind will give protection against all kinds of dusts, fumes, smokes, mists, gases, and vapors. Such respirators are nonemergency devices. Common uses for them are protection during abrasive blasting, metal spraying, and other situations where protection is needed for the head and neck as well as for the respiratory organs.

Air-Purifying Respirators. The common air-purifying devices may be divided into two broad groups as regards their mode of action and the classes of contaminants against which they protect. These are (1) mechanical-filter respirators, and (2) chemical-filter respirators. There is also a third class which is a combination of 1 and 2. Mechanical-filter respirators protect against particulate contaminants (dusts, fumes, mists, and smokes) and chemical-filter respirators against gaseous contaminants (gases and vapors).

The common design of a *mechanical-filter respirator* consists of a filter element in the form of discs, a bag or bags, or a cylinder or cylinders attached directly to a half-mask facepiece in such a manner that the inspired air passes through the filter material. A very few designs have full- or half-mask facepieces, or mouthpieces, attached by a flexible breathing tube to the filter worn on the chest, on the back, or at the side of the person.

Mechanical-filter respirators operate on the principle of removing some or most of the particulate contaminant from the inhaled air by physical trapping and electrostatic attraction. There is a large variety of forces at work in the removal of dusts, fumes, mists, or

smokes from the air passing through mechanical filters. The filtering efficiency and the resistance to air flow increase as the filter is used in contaminated air, owing to the collection of the contaminant in the filter material. Hence, just as for cloth filter collectors (see Chapter VII), a mechanical-filter respirator provides its poorest protection when new or after cleaning. It likewise affords the lowest resistance to breathing at the same time. The usable cycle or period is, therefore, determined by the time required for the filter to plug to such an extent, where breathing becomes uncomfortable or laborious.

Mechanical-filter respirators may be subdivided conveniently into the following types (based on Bureau of Mines approvals):

1. Dust respirators.
   a. Fibrosis-producing and nuisance dusts.
   b. Toxic dusts.
   c. All dusts.
2. Fume respirators.
3. Mist respirators.

There is in addition a large group of respirators not approved by the Bureau of Mines, any of which provides some protection against any or all classes of particulate contaminants. This subject will be covered in more detail later.

The fundamental difference in the foregoing classes of respirators is one of filtering efficiency. Any mechanical filter removes a certain percentage of any particulate contaminant from the air passing through it; the better the filter the higher the percentage removed. The difficulty of contaminant removal is largely a function of the particle size of the contaminant so that fumes (size range in the order of 0.1 to 0.5 micron) are much more difficult to remove than the larger size materials (dusts and mists). In addition the adequacy of a respirator is based on the amount of contaminant getting through it rather than on the percentage filtration. Hence a higher filtering efficiency is required for Bureau of Mines approval in a toxic dust than in a fibrosis-producing dust respirator, since toxic dusts are more harmful unit for unit than fibrosis-producing dusts. In general, if a respirator is approved by the Bureau of Mines for a certain dust or type of dust, it is considered to be approved also for any other dust that is not smaller in size and no more harmful in nature than the dust for which approved. Therefore a respirator approved for silica dust is also approved for all fibrosis-producing

and nuisance dusts; one approved for lead dust is also approved for other toxic or poisonous dusts; and one approved for both lead and silica dusts is considered to be approved for all dusts. In its approval label or certificate of approval the Bureau of Mines designates the materials for which a respirator is approved (see figures 149 and 150).

Mechanical-filter respirators are nonemergency devices. They provide *no* protection against gases and vapors. This fact must be borne in mind when dealing with mists of volatile liquids and with dusts of materials that give off vapors. If significant amounts of vapor are present the mechanical filter must be supplemented with a suitable chemical filter, or a different type of respirator (air-line) must be used. The following are some examples of uses of mechanical-filter respirators: welding and cutting operations; grinding and handling all types of dusty materials; house cleaning and maintenance work; spray coating with enamels or glazes; drilling, mucking, and transporting rock in mines, tunnels, and quarries; cutting and polishing stone; shaking out and grinding castings; following dust-producing farm implements; applying lime to soil and threshing soil-contaminated grain; ash handling; and using poisonous dusts and sprays as insecticides and fungicides. It must always be remembered, however, that respirators of any kind, and in particular routine or nonemergency devices, are adjuncts to, not substitutes for, other engineering-control measures. There is a certain amount of discomfort associated with the wearing of respirators continuously for long periods of time. They are, therefore, best suited for intermittent exposures of short duration, rather than for continuous use.

Chemical-filter respirators can best be discussed in two groups: gas masks and chemical-cartridge respirators.

Gas masks consist usually of a full-mask facepiece connected by a flexible breathing tube to a canister that is carried on the chest or back of the wearer. Some gas masks have the canister (usually small-size canister) attached directly to the facepiece. The canister is filled with chemicals, usually in granular form, which remove the toxic gases or vapors from the air by chemical or physical reaction. These devices are intended primarily for protection against gaseous contaminants but may include filters for particulate contaminants also (see next section).

The gases or vapors against which a gas mask will give protection depends entirely on the contents of the canister. Fortunately, how-

ever, it is not necessary to have a different chemical sorbent for every different gaseous contaminant, because chemical substances can be

PERMISSIBLE

UNIVERSAL GAS MASK

APPROVAL DEPARTMENT OF THE INTERIOR · SAFETY · EFFICIENCY · MINERAL INDUSTRIES · BUREAU OF MINES **NO. 1400**

ISSUED TO THE

MANUFACTURER'S NAME

Address

Approved for respiratory protection in atmospheres containing 16 percent or more of oxygen or in which a flame safety lamp will burn, and not more than 2 percent acid gases, organic vapors, or carbon monoxide (see "CAUTION" on canister label regarding hydrocyanic acid gas); 3 percent ammonia; or 2 percent total of poisonous gases when more than one class is present. The canister contains a special filter and is approved for respiratory protection against toxic dusts, fumes, mists, fogs and smokes.

The approved assembly consists of: BM-1400 canister, BM-1400 timer, BM-1400 harness, and BM-1400 facepiece.

CAUTION

1. Return to fresh air immediately if flame safety lamp goes out, if irrespirable or irritating gases are noticed, or if symptoms of distress are experienced
2. The nominal service time of each canister for protection against carbon monoxide is 2 hours of total use whether carbon monoxide is present or not; change canister after 2 hours of total service or sooner if irrespirable gases are noticed by the wearer.
3. Read instructions on canister label and on card in lid of mask case.

FIGURE 149. Universal Gas-Mask Approval Label (*Courtesy Bureau of Mines*)

grouped to some extent in accordance with their chemical and physical reactivity with sorbents. On this basis the Bureau of Mines developed a practical classification of gas-mask canisters and a color

code for use in its schedule[4] of requirements for gas-mask approvals (see table 39). This is now an American standard and is used by all gas-mask manufacturers in the United States. It is apparent from

PERMISSIBLE RESPIRATOR
FOR
DUSTS

APPROVAL NO. 2100

ISSUED TO THE
MANUFACTURER'S NAME
Address

Approved for protection against the inhalation of dusts (dispersoids or particulate matter formed by the disintegration of solid materials by such processes as crushing, grinding and abrading).

The approved assembly consists of: BM-2100 facepiece and BM-2100 filter.

In making renewals or repairs, parts identical with those furnished by the manufacturer under the pertinent approval shall be maintained.

CAUTION

This respirator removes only dispersoids from the air. It gives no protection against gases, vapors, or an insufficiency of oxygen.

Follow the manufacturer's instructions for fitting the respirator to the face, for cleaning or changing the filter, for cleaning the respirator, and for caring for it while not in use.

FIGURE 150. All Dust Respirator Approval Label (*Courtesy Bureau of Mines*)

the table that canisters may furnish protection for one specific gas or class of gases or for a combination of gases or classes thereof.

Gas masks that will give protection against any known harmful gas or vapor are available commercially. Devices approved by the Bureau of Mines protect against as much as 2% by volume of acid

gases, organic vapors, and carbon monoxide and 3% by volume of ammonia. These are high concentrations of gaseous contaminants; for acid gases and ammonia about as high as can be endured by the thin-skinned areas of the body. Gas masks are designed primarily for emergency situations but will give good protection for relatively long periods of time against the exposures encountered in nonemergency situations.

TABLE 39

GAS-MASK IDENTIFICATION CODE

Canister—Type Letter	*Contaminants Protected Against*	*Colors*
A	Acid gases	White *
B	Organic vapors	Black *
C	Ammonia	Green
D	Carbon monoxide	Blue
AE, *BE*, etc.	Dusts, fumes, mists, fogs, and smokes in combination with any of the above gases or vapors	One-half-inch contrasting black or white stripe around the canister near the top
AB	Acid gases and organic vapors	Yellow
ABC	Acid gases, organic vapors, and ammonia	Brown
N	All of the above atmospheric contaminants	Red. (Filters are included in this canister, but stripes to indicate them are unnecessary)

* Canisters for a single gas or vapor other than ammonia or carbon monoxide shall have a ½-in. colored stripe around the canister near the bottom. The color of the stripe will be assigned.

There is one very important precaution to be kept in mind when dealing with the use of gas masks in emergency situations. These protective devices are merely air purifiers and do *not* protect the wearer against an atmosphere deficient in oxygen. Many deaths have resulted from the use of canister gas masks in emergency situations where the atmosphere, unknown to the would-be rescuers, was deficient in oxygen.[137]

Some common examples of the use of gas masks are the operation of chemical processes; handling volatile or gaseous chemical products; repairing refrigerating systems; working around tanks or similar vessels containing poisonous products; fire fighting; and fumigating.

Chemical-cartridge respirators usually consist of a small cartridge-like filter attached directly to, and carried by, a facepiece of half-mask design. Sometimes full-mask facepieces are used and in other

instances they have a mouthpiece attached directly to the cartridge and a wire clip to close the nose. Notable among the mouthpiece type is the so-called "carbon monoxide self-rescuer," which is used very widely in "gassy" mines and has saved many lives. Chemical-cartridge respirators are actually low-capacity or junior-size gas masks. They are designed for the nonemergency use of giving protection against atmospheres which workmen may breathe without protection but which will either produce discomfort or a chronic type of affection or poisoning after repeated exposures of several hours daily. While not intended for work of a general emergency character, the small size of these devices makes them convenient for carrying in the pocket or hanging from the neck or clothing of workmen. From this position they are readily available and permit making rapid emergency shutoffs of equipment and escaping from contaminated atmospheres.

Some of the common uses of these devices are protection from the vapors of solvents encountered during operations, such as spray coating, degreasing, dry cleaning, and using rubber cements; and protection from low concentrations of acid gases as in smelting of sulfide ores and in many chemical processes where contact with small amounts of harmful gases and vapors is practically unavoidable.

Combination air-purifying respirators include a mechanical filter for protection against dusts, fumes, mists, and smokes, and a chemical filter for protection against gaseous contaminants. Respirators of this type are available commercially for situations such as gas masks with smoke filters for fire fighting; and chemical-cartridge respirators with integral or replaceable mechanical filters for spray painting, metallurgical operations, and for welding and cutting operations.

Respirable Air Supply. An adequate supply of air that is safe to breathe, free from objectionable odors and nuisance substances, and comfortable from the standpoint of temperature and humidity is a basic requirement for the satisfactory use of all supplied-air respirators of the hose or air-line type. In practice, the compressed air supplied to such devices frequently does not meet these requirements. Rust, scale, water mist and slugs, and oily mists and odors occur very frequently in compressed-air systems. Furthermore, if compressors run hot, the oil may be decomposed with the formation of smoke, gases with acrid properties, and possibly carbon monoxide and a serious oxygen deficiency. There are also possibilities of contamination of the compressor or blower intake air if proper precautions are

not observed as regards the location of the intakes to these devices.

The precautions to be taken with high pressure or internally oil-lubricated types of air suppliers are (1) good maintenance, (2) operation at low temperature and the installation of indicators or alarms to warn the operator of overheating, and (3) location of the air intake in an area of unquestionably clean air.

Air cleaners and conditioners are available for removing oil, odors, rust, water, scale, etc., from the air supplied to respirators of this type. These cleaners and conditioners, while helpful, have their limitations and leave much to be desired. It is much better to have an air-supply system which does not contaminate the air than to try to purify it with the cleaners or conditioners available on the market today. Furthermore, none of these devices removes carbon monoxide or overcomes an oxygen deficiency. The proper tempering and humidification of the air reaching the mask, hood, or helmet is also very important particularly in cold weather and in dry regions.

Low-pressure air suppliers (blowers, pumps, and semicompressors) are available commercially. Such devices have many advantages over the usual compressors and are to be recommended as sources of air for supplied-air respirators. Where a number of such respirators are used it is advisable also to use a distribution system entirely independent of the compressed air system, since in such a system it is easier to maintain an adequate supply of clean air at constant pressure and without the use of pressure-reducing mechanisms.

Bureau of Mines Approval. The U. S. Bureau of Mines approves respiratory protective devices of most types if they pass the tests specified in their approval schedules.[3, 4, 138, 139, 140] Devices so approved are stamped with the approval number and the containers are marked with a reproduction of the certificate of approval which specifies what it is approved for. Many devices, particularly of the nonemergency type, have not been approved by this agency. Possibly some such devices would pass the tests if submitted to the Bureau; the majority, however, could not pass the approval tests. This does not necessarily mean that unapproved devices do not provide adequate protection for any purpose. As indicated earlier, any filter-type respirator will remove a certain percentage of the appropriate contaminant from the inspired air; mechanical filters remove only particulate contaminants, and chemical filters remove essentially only gaseous contaminants. Hence, if the worker's exposure is not severe, a respirator less efficient than required to meet the rather

severe tests of the Bureau may provide adequate protection to the wearer, and there are numerous situations throughout industry where unapproved respirators may be used safely. However, unless trustworthy data on the degree of exposure and filtering efficiency of the respirator in question are available, it is frequently impossible to say whether it will provide adequate protection. It is, therefore, a very good policy to recommend only Bureau of Mines approved respirators if such devices are available.

Bureau of Mines approval tests are very thorough as is evident from a study of any of the approval schedules. In addition to filtering adequacy, other items, such as comfort, practicability, ruggedness, resistance to breathing, suitability of construction materials, and numerous similar features, are considered. These approval tests have done much to improve the standards of product quality, to encourage the use of only safe and suitable equipment, and to instruct the wearer in the proper use of such devices.

From time to time the Bureau issues lists of approved devices. These are very useful to the purchaser in the selection of suitable protectors. According to a fairly recent list,[141] the following devices have been approved: 7 self-contained breathing apparatuses; 9 gas masks for acid gases, 6 gas masks for organic vapors, 5 gas masks for both organic vapors and acid gases, 11 gas masks for ammonia, 1 self-rescuer for carbon monoxide, 5 gas masks against all gases and vapors (Universal), and 3 gas masks against all gases and vapors and with smoke filters; 8 hose masks with blowers; 2 hose masks without blowers; 3 air-line respirators; 6 abrasive-blasting respirators; 27 respirators for fibrosis-producing and nuisance dusts, 9 respirators for toxic dusts, and 15 respirators for all dusts; 3 respirators for fumes; and 8 respirators for pneumoconiosis-producing dust and mist and chromic acid mist. While not included in reference 141, it is known that a few chemical cartridge respirators have been approved for organic vapors under the Bureau's most recent schedule.[140]

Selection of Respirators. The use of respiratory protective devices as a control procedure requires as much consideration as any other control method. In the selection of a respirator, thorough consideration should be given to the various factors involved, such as (*a*) the chemical, physical, and toxicological properties of the substances against which protection is required; (*b*) the effect of the processes and conditions of use of the substances as they relate to the possible formation of significant secondary products; (*c*) the processes and conditions of their use as they relate to the dissemination of contami-

nants; (*d*) an evaluation of actual and potential hazards to determine whether conditions immediately dangerous to life or death might arise or whether injurious effects would be produced only after prolonged or repeated exposures; (*e*) the nature of the duties to be performed by the wearer of protective devices as they relate particularly to restriction of movements; (*f*) an understanding of the principles, design, scope of use, limitations, advantages, and disadvantages of the respiratory protective equipment available.

Virtually all applications of respiratory protective devices are specific and require individual attention. Examples of typical conditions with indication of choice of appropriate respiratory protection follow.

Atmospheres deficient in oxygen may be extremely hazardous and immediately dangerous to life. Only oxygen-breathing apparatus or a hose mask with blower should be chosen for protection under such conditions. Final choice between these two devices will depend on working conditions.

For example, for rescue work in mines, the men must proceed for considerable distances from a source of fresh air. Obviously, hose masks would not be satisfactory, as wearers are limited to a distance of 150 ft; therefore, oxygen-breathing apparatuses must be used. However, for use in entering confined spaces, such as tanks and manholes, hose masks are generally preferred because they are easier to maintain and relatively little training is required to use them. Air-purifying devices should never be worn in atmospheres deficient in oxygen.

Either oxygen-breathing apparatuses or hose masks with blowers are the logical choice for very high concentrations of toxic gases and vapors (exceeding 2 or 3%), and again final selection will depend on working conditions. Although gas masks might afford some protection, they would not be a good choice, because very high concentrations indicate a confined space with possibility of low oxygen; moreover, the absorbents would be used up rapidly. The marked discomfort produced by such irritating gases as ammonia and sulfur dioxide and the danger of poisoning through the skin by absorption of hydrogen cyanide limit the concentrations that can be entered.

For moderately high concentrations of toxic gases and vapors (2% or less) oxygen-breathing apparatuses would, of course, be applicable, as would hose masks with blowers and gas masks. Owing to their weight and maintenance and training requirements, oxygen-breathing apparatuses probably would not be used. The hose mask would be

satisfactory and might be chosen if the encumbrance of the hose line were not too great. The most probable choice would be a gas mask, because of its light weight, ease of maintenance, and the small amount of training required by the wearer. The appropriate canister should, of course, be chosen (see table 39).

Low concentrations of toxic gases and vapors are atmospheres that can be breathed without protection but that will produce discomfort and possible chronic injury after repeated exposure to them. Hose masks and oxygen-breathing apparatuses would give satisfactory protection, but they would be given little consideration for such a situation for the reasons already outlined. Gas masks, chemical-cartridge respirators, or air-line respirators would be satisfactory. Final choice would depend on actual conditions and freedom of movement required by the worker.

For pneumoconiosis-producing and nuisance dusts, air-line respirators, pneumoconiosis-producing and nuisance-dust respirators, or all-dust respirators could be chosen. If the dust concentration is exceedingly high, air-line respirators would be preferable. If the conditions of work are such as to interfere with the use of an air line, mechanical-filter respirators will serve satisfactorily, even though they are awkward to wear for many kinds of work.

For toxic dusts, air-line respirators, toxic-dust respirators, or all-dust respirators would be a logical choice. The final decision will depend on local conditions of work and the materials being used. Knowledge of the concentrations likely to be encountered and of the safe or permissible concentration is necessary in evaluating the protection afforded.

Fume is particulate matter formed by volatilization and condensation, as in lead burning. Fume is defined because it is a term used loosely to refer to gases, vapors, and particulate matter. Such usage is confusing and may lead to serious injury if a mechanical-filter fume respirator is used for protection against some toxic gas or vapor against which it affords no protection. For fume as defined above, air-line respirators or mechanical-filter fume respirators would be the logical choice, and the final decision would depend on local working conditions.

Frequently, protection must be afforded against a *combination of gases and particulate matter.* If the atmosphere is not immediately dangerous to life, air-line respirators are generally recommended. However, gas masks equipped with a suitable filter, or cartridge respirators equipped with a suitable filter may be used. The final

decision not only would depend on the local conditions of work as they relate to freedom of movement but also on thorough consideration to ascertain whether gas masks or cartridge respirators would give the desired protection.

Much of the information needed to make an intelligent choice of a respirator is summarized in table 40 for the convenient use of industrial hygiene engineers.

Use and Care of Respirators. No matter how well a protector is designed or how good a performance it is capable of giving it must be properly cared for and maintained in good condition in order to obtain satisfactory protection from its use. This is the most important factor in the use of these devices and yet the most frequently neglected one, particularly for nonemergency respirators since the results of such neglect are not so readily evident. Proper use, care, and maintenance require a thorough knowledge of the device and should be performed by, or at least under the supervision of, a responsible and capable person. All respirators should be inspected periodically whether used or not and should be serviced completely after each use.

When a respirator is given to a worker, he should be told why he needs to wear it, he should be shown how to wear it, he should be told what provisions are in effect to clean the respirator daily and to insure that he will always get the same device. To accomplish this last provision it is necessary to mark each worker's respirator with an identification of some sort such as the worker's initials or employment number. All respirators used routinely should be collected at a central point at the end of each shift for cleaning. Various procedures are in vogue for this purpose.[43, 142, 143] If these respirators can be serviced between shifts only one respirator per workman is needed; if the cleaning is done during the work shift two respirators are needed for each worker. Clean cabinets are needed at convenient locations for storing the respirators while not in use, for example, during the lunch period.

Respirators, particularly the facepieces, should be scrubbed daily after use with lukewarm water and soap. This not only is good hygienic practice but also prolongs the life of the rubber, or otherwise the dirt, oil, and perspiration from the face may cause rapid deterioration. Respirators should also be disinfected at regular intervals. If a respirator is worn by the same person, disinfection once a week probably should be satisfactory in most instances, depending on conditions of use and thoroughness of cleansing with soap

TABLE 40

Respirator	*General Design Features*	*Protection Provided*
I. Supplied-air respirators	Wearer separated from his immediate atmosphere and supplied respirable air from another source	Against any atmosphere not dangerous because of skin absorption
A. Self-contained breathing apparatus	Source of air or oxygen carried by wearer in suitable equipment. Accessories as needed, such as pressure reducing valves, reservoir, CO_2 absorbent, mouthpiece, nosepiece, and cooler	Against any atmosphere
B. Hose mask with blower	Blower (manual or power operated), large-diameter hose, harness, and facepiece	Do
C. Hose mask without blower	Large-diameter hose, harness, and facepiece	Against any atmosphere, but should not be used in immediately harmful atmosphere
D. Air-line respirators	Air supplied from special system or compressed air line to wearer through small-diameter high-pressure hose, reducing valve, short piece of flexible rubber tubing and facepiece	Do
E. Abrasive blasting respirator	Features same as *B*, *C*, *D* above (*D* is more common), but in addition this device has suitable hood to protect wearer against rebounding abrasive	Same as *B*, *C*, or *D* above, depending upon features, but in addition has protection against impact and abrasion from rebounding abrasive material
II. Air-purifying respirators	Filter (chemical or mechanical, for removing contaminant or contaminants from inhaled air) and facepiece attached directly or by means of short length of flexible rubber tubing. Entire device is carried by the wearer	Against specific contaminants or types of contaminants. No protection against atmospheres deficient in oxygen
A. Mechanical-filter respirators (commonly called dust respirators)	Fibrous filter attached to half-mask facepiece directly or by means of a short length of flexible rubber tubing	Against particulate contaminants
1. Dust	Do	Against dusts of all kinds
2. Fume	Do	Against fumes of various metals. Since fumes are probably more difficult to remove by mechanical filtration than other kinds of particulate matter, with the possible exception of smokes, this respirator will protect against such particulate matter as dusts and mists
3. Mist	Do	Against mists as produced by spray coating with paint and vitreous enamels, chromic acid mist as produced in chromium plating, and mists of other materials whose liquid vehicle does not produce harmful gases or vapors

TABLE 40 (*Continued*)

Respirator	*General Design Features*	*Protection Provided*
B. Chemical-filter respirators	Canisters or cartridges containing suitable chemicals attached directly or by means of short length of rubber tubing to full facepiece or half mask	Against gaseous contaminants
1. Gas mask	Canisters with chemicals for individual gases or combinations thereof	Up to 3% ammonia and 2% most other gases and/or vapors
2. Chemical-cartridge respirators	Cartridges with chemicals for individual gases or combinations thereof	Against very low or nuisance concentration of gases and/or vapors
C. Chemical- and mechanical-filter respirator	Chemical- and mechanical-filter attached to facepiece directly or by means of a short length of flexible rubber tubing	Against combinations of gaseous and particulate contaminants

and water. A respirator that has been worn once should be disinfected before it is given to another person to wear.

There are several procedures for disinfecting respirators; however, as certain respirator parts may be damaged by the disinfecting agent, the manufacturer should be consulted as to the best procedure for his device.

Common disinfecting procedures include scrubbing or immersing the respirator for 10 minutes in 70% alcohol, 2% cresol, or a solution of formalin made of mixing 1 part of 40% formaldehyde in 9 parts of water. When such agents as cresols are employed as disinfectants, the parts that come in contact with the skin should be rinsed thoroughly with water, as some persons are highly sensitive to such materials.

Cleaning and disinfecting afford an opportunity for cleaning or replacing filters, inspecting valves, headbands, facepieces, and metal parts that might be distorted.

PROTECTIVE CLOTHING

In addition to respirators, protective clothing of various kinds is helpful in the prevention of occupational diseases, particularly dermatitis. Since the subject of protective clothing for the prevention of dermatitis has been so ably covered elsewhere[144] it will not be discussed here.

Some materials, such as tetraethyl lead, trinitrotoluene, aniline, nitroglycerin and methyl alcohol, may be absorbed through the skin in harmful quantities. To prevent this it is necessary to avoid skin contact as much as possible. This is accomplished as completely as

possible by engineering and safety measures which for material in solid form such as trinitrotoluene can seldom be wholly satisfactory. Also in many operations dealing with nitroglycerin it is difficult to keep the workers from handling the material with their bare hands.

To prevent excessive skin absorption of such substances it is necessary to provide the workers with appropriate protective clothing such as complete changes of work clothes, which are laundered daily for TNT workers, and tight-fitting gloves, which are changed at least once daily (frequently oftener) for workers handling nitroglycerin. Even though absorption by inhalation is more important, in most instances, than skin absorption, the amount entering the body through the skin if proper precautions are not taken may mean the difference between cases of illness on the one hand and no such experience on the other.

CHAPTER XIII

HEATING, VENTILATING, AND AIR CONDITIONING FOR TEMPERATURE, HUMIDITY, COMFORT, AND ODOR CONTROL

This chapter must of necessity deal with the subject matter in piecemeal fashion lest it become lengthy and include much discussion which is only of minor interest to industrial health engineers and many plant engineers. By far the most important problem in this category to industrial hygiene personnel is that of keeping the workers in hot industries relatively cool and of cooling the air in all industries in hot weather. Of concern also are the ventilation and air conditioning of work spaces such as office buildings and some factories in which the major problem is the contamination of the atmosphere by the occupants.

Heating, and for that matter ventilating, of work places in cold weather seldom poses a problem to the industrial hygiene engineer. Practically every factory needing it is equipped, more or less automatically, with a heating system. Also that phase of heating, ventilating, and air conditioning which pertains to the requirements of the processes and quality control is not generally within the scope of industrial health engineering and will not be discussed. Those who have need for such information should consult a standard reference such as 2. However, the quality control and process requirements as regards temperature and humidity often create an atmospheric condition which is of concern since it requires heating, cooling, or dehumidifying the air or the worker in the interest of his health and efficiency. It must be borne in mind also that this chapter embraces only those conditions caused by temperature and humidity and by the contaminants produced by the occupants, not contaminants produced by processes; they were discussed elsewhere.

Very briefly then there are only two, but highly important, phases of the chapter subject matter which are of real concern to industrial hygiene personnel. These will be discussed herein. They are briefly as follows:

1. Cooling or dehumidifying the air or cooling the workers in hot industries or during hot weather in the interest of their health, efficiency, well-being, and comfort.

2. Controlling within prescribed limits the various factors or qualities of the air to promote the efficiency and comfort of workers in spaces where the only or major source of contamination is the occupants.

A few of the terms employed in the following discussion are used very loosely at present and will, therefore, be defined at the outset to prevent confusion or misunderstanding.

1. *Effective temperature* is an empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity, and air movement.[145, 146] (Since a given effective temperature expresses the same degree of warmth as still, saturated air having the same dry-bulb temperature it is usually significantly lower than the dry-bulb temperature for a given set of conditions.) See figures 151–153.

2. *Humidity* unless otherwise expressly stated will mean the relative humidity in percentage.

3. *Air conditioning* will mean the simultaneous control of all or at least the first three of those factors affecting both the physical and chemical conditions of the atmosphere within any structure. These factors include temperature, humidity, air motion, air distribution, dust, bacteria, odors, toxic gases, and ionization, most of which affect in greater or lesser degree human health and comfort.

4. *Ventilation* is the process of supplying or removing air by natural or mechanical means to or from any space. Such air may or may not have been conditioned.

Promoting the Efficiency, Health, and Comfort of Workers in Hot or Humid Industrial Environments. It has been shown that the output efficiency of workers decreases considerably when the temperature of their environment increases above certain limits and that their peak in efficiency is obtained when the temperature is within prescribed limits which vary with the severity of the work.[2, 147, 148, 149, 150] Thus in one instance men were found to perform 28% less physical work in an atmosphere of 86° F dry bulb and 80% humidity than in one of 68° F and 50% relative humidity. In another instance the maximum seasonal fluctuation in output was found to be about 30% below the usual production, and this fluctuation occurred in summer. Studies conducted at the ASHVE Research Laboratory demonstrated that (1) men at hard work (90,000 ft-lb per hour) are unable to compensate physiologically for the increased heat production at effective temperatures above 80° F, (2) for subjects at rest the upper limit of man's ability to compensate for

atmospheric conditions is about 90° effective temperature, and (3) the comfort zone of men normally clothed and working at 33,075 ft-lb per hour is 46° to 64° effective temperature, and the comfort line is 53° effective temperature (ET). On the basis of these findings it becomes apparent what a high price industry must pay in terms of decreased production for high atmospheric temperatures.

It has been shown elsewhere also that the accident frequency rate is influenced by the temperature of the workers' environment, being lowest when the worker is comfortable and rising sharply as the temperature moves in either direction.[151]

The large amount of data in the literature on this subject seem to prove conclusively that it is poor economics not to control the heat wherever this is practicable. The temperature to be aimed at is the comfortable effective temperature since workers are most efficient when working in the comfort zone of the effective temperature index as indicated previously. These temperatures vary from about 71° ET in summer for sedentary workers to some value in the forties for very hard labor (53° ET for work at 33,000 ft-lb per hour). While these goals may not be attained it is well worth while from the dollars and cents viewpoint to cool the air of workspaces in summer as much as is feasible.

While the foregoing discussion pertained to conditions which involved only comfort and efficiency, there are many industries commonly referred to as the hot industries where the heat needed for production or incident thereto is of such magnitude that it creates atmospheric conditions which are at times definitely harmful to the worker. There are certain maximum temperatures above which the average worker cannot compensate for the atmospheric conditions; these temperatures varying inversely with the severity of the labor. These suggested maximum values are about 87° ET for light or sedentary work and 80° for manual labor.[147, 152] In Massachusetts a value of 86° ET is used as the maximum allowable temperature above which control measures should be employed to reduce it.[153]

There are many operations in the hot industries, such as certain mines and factories and the steel, glass, and foundry industries at which the atmosphere generally cannot be made to conform to these suggested maximum temperatures. The worker also frequently receives considerable heat by radiation from nearby hot objects. Under such conditions the only satisfactory solution lies in cooling the worker not the atmosphere. This can be done by (1) decreasing the heat he receives through radiation by means of shields, insulation,

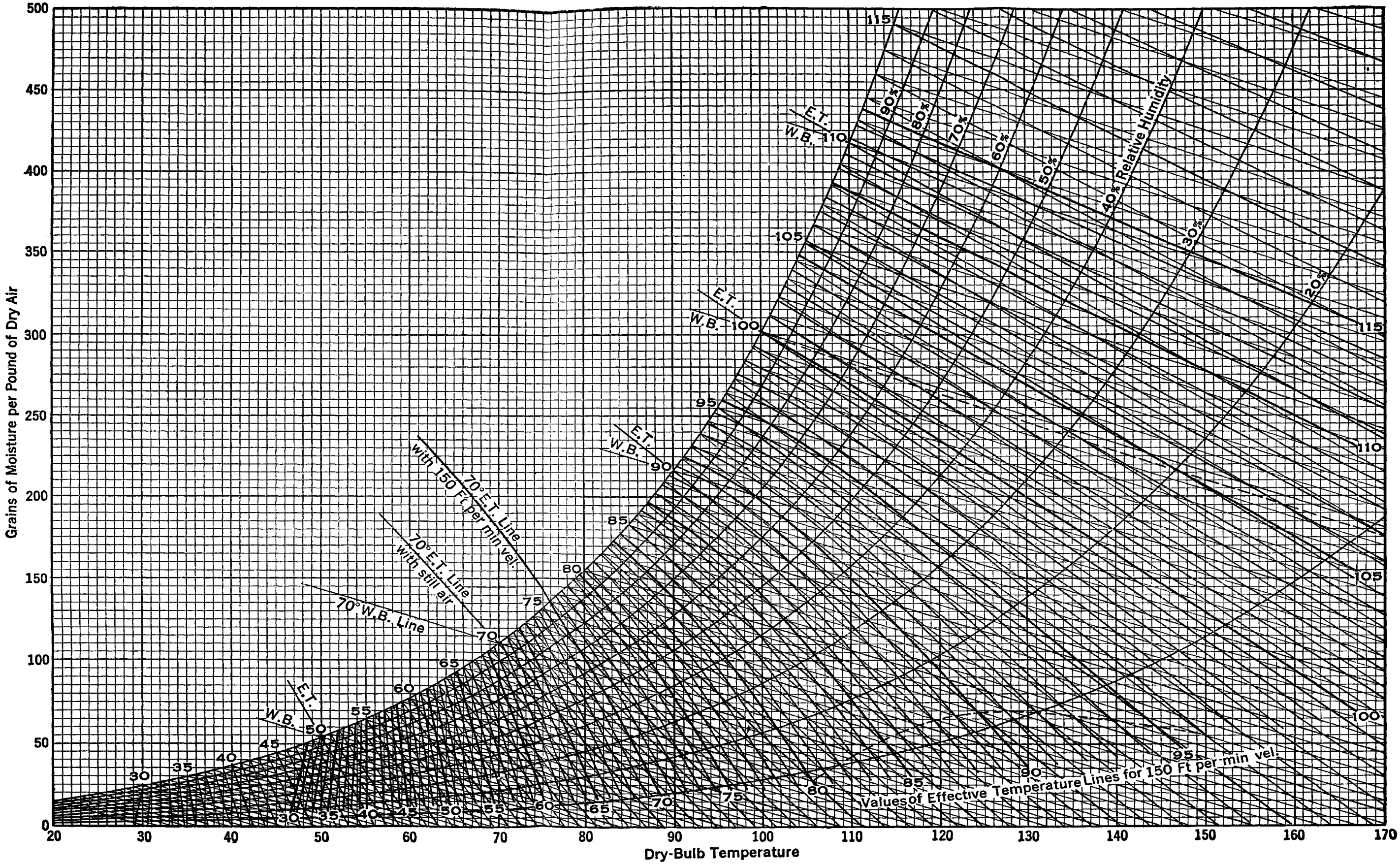


FIGURE 151. Effective Temperature Chart for Air Movement of 150 FPM. (*From Heating Ventilating Air Conditioning Guide 1939*)

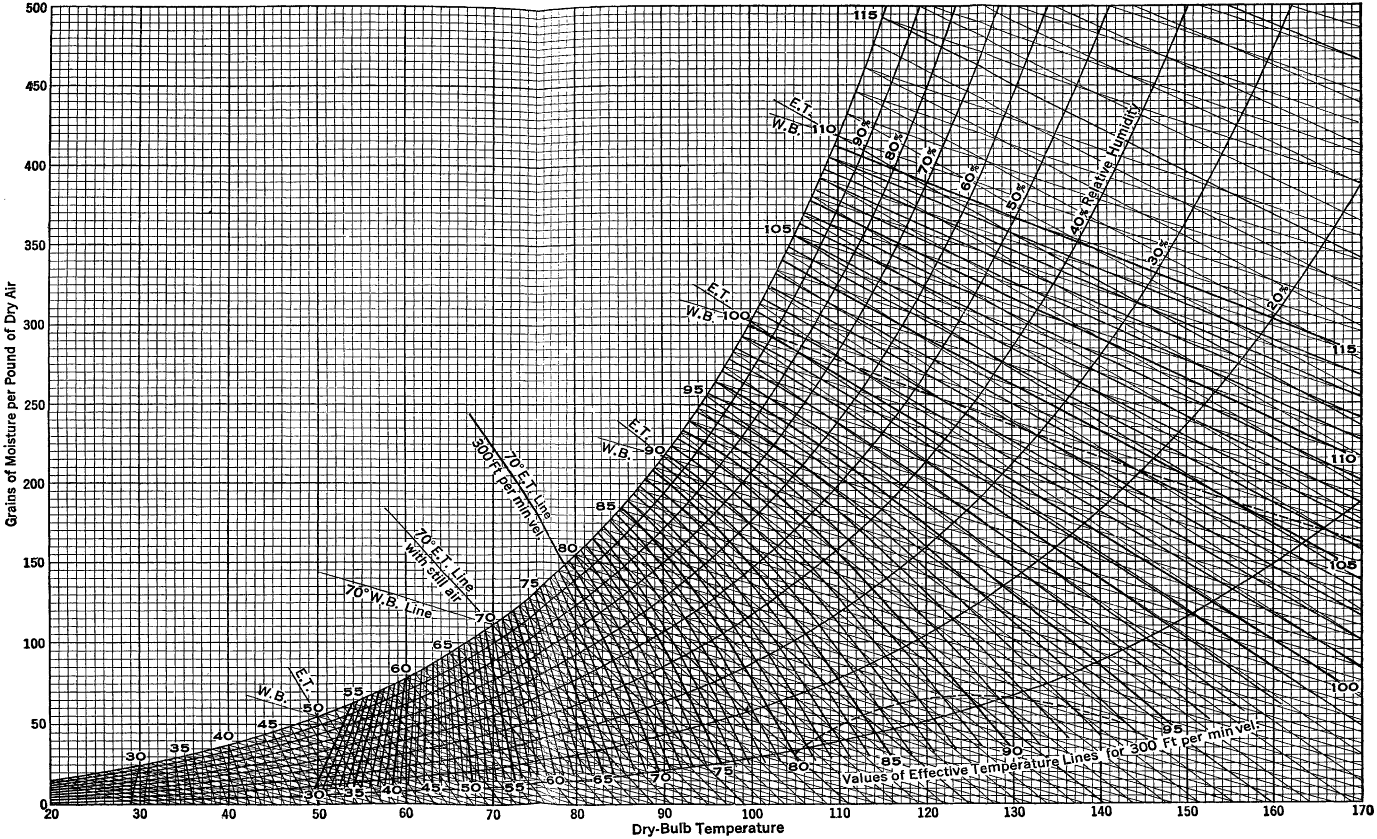


FIGURE 152. Effective Temperature Chart for Air Movement of 300 FPM. (*From Heating Ventilating Air Conditioning Guide 1939*)

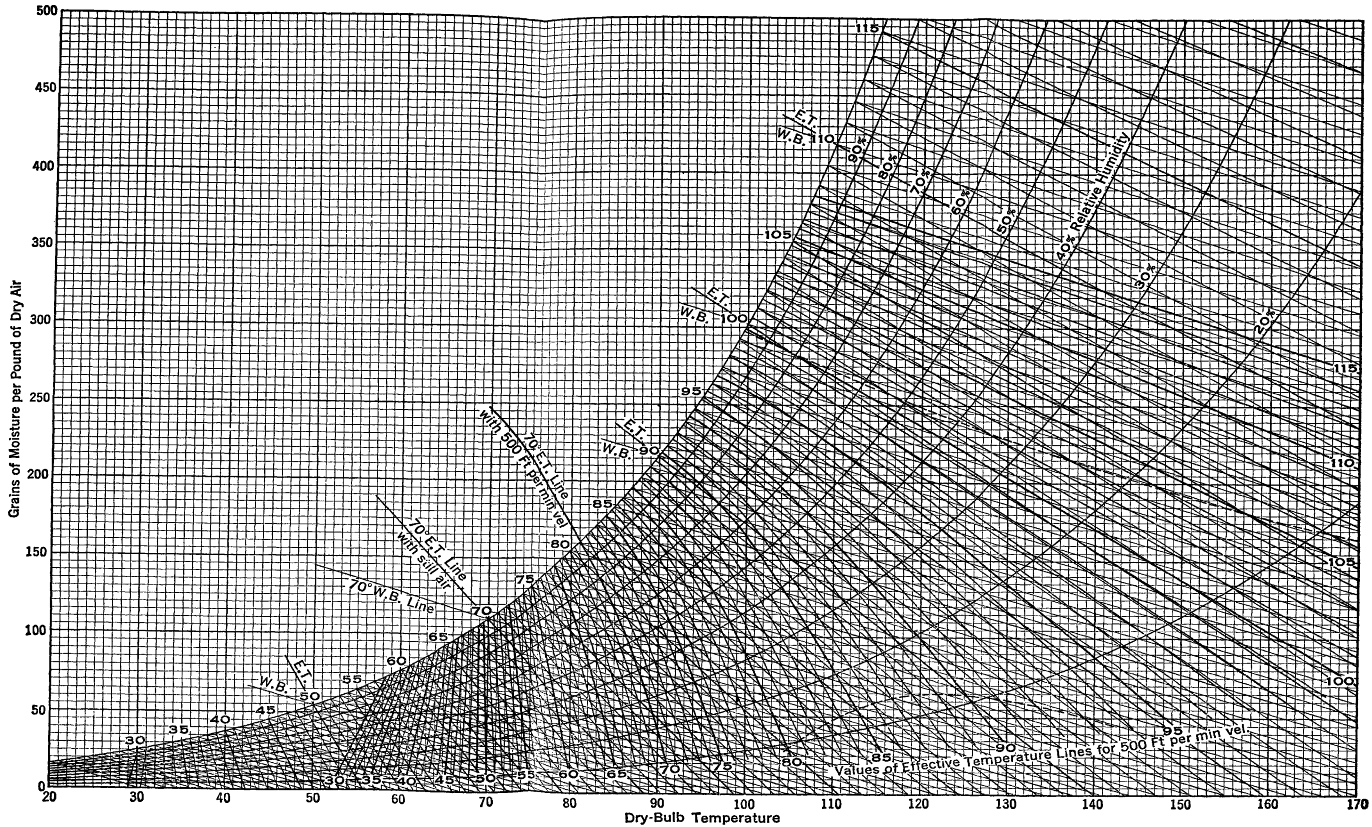


FIGURE 153. Effective Temperature Chart for Air Movement of 500 FPM. *(From Heating Ventilating Air Conditioning Guide 1939)*

and the like, and (2) cooling him by blowing air over him. Since the first approach deals with radiant energy it will be covered in Chapter XIV. Cooling the worker by "spot blowing" is very useful as long as the air blown over him is not hot enough to produce a heating rather than a cooling effect.

The effective temperature index provides the engineer with a very useful tool in deciding the best approach to the problem of cooling the worker. In addition to an understanding of the effective temperature index, it is necessary to know what physiological reaction is produced by heat, humidity, and air movement. The necessary fundamental relationships in this connection may be summarized as follows: [147]

1. In general, moving air exerts a cooling effect on the human body as long as the wet-bulb temperature remains below body temperature irrespective of the dry-bulb temperature. When the wet-bulb temperature is above that of the body, air motion has a heating effect.
2. For ordinary temperatures maximum cooling at any velocity occurs at saturation, while above body temperatures maximum heating occurs with saturated air.
3. For ordinary temperatures, the higher the velocity, the more predominant becomes the dry-bulb temperature as an index of comfort. There is a definite temperature depending upon the velocity of the air at which comfort is independent of wet-bulb temperature or relative humidity. Below this temperature, the higher the humidity, the cooler the condition, while above this temperature the higher the humidity, the warmer the condition.
4. At high temperatures when the surface of the body is completely covered with perspiration, the higher the velocity, the more predominant becomes the wet-bulb temperature as an index of comfort.

These fundamental laws point to one very important fact which is sometimes not recognized in attempting to cool workers in hot industries or at hot operations. It is that when the wet-bulb temperature of the air is higher than that of the body, blowing air over the worker does *not* cool him, it heats him even more and increases his discomfort. Therefore, in industries such as hot mines and in glass plants, steel mills, and other hot industries in hot humid summer weather, it is frequently inadvisable to merely blow air over the worker; it must be cooled or dehumidified also.

In figures 151–153 are given data on the interrelationship of dry-bulb, wet-bulb, and effective temperatures, humidity, and air motion of 150, 300, and 500 fpm and of still air. Hence, if the dry-bulb and wet-bulb temperatures are known, and if the velocity of the air is essentially zero, 150, 300, or 500 fpm, the effective temperature may

be read directly from the appropriate figure. For example, the still-air effective temperature of a condition in which the dry-bulb is 90° and the wet-bulb is 75° is 80°. These same dry-bulb and wet-bulb temperatures produce effective temperatures of 77, 75½, and 73½°, respectively, at air movement rates of 150, 300, and 500 fpm. For other rates of air movement, namely, 50, 100, 200, and 700 fpm, the effective temperatures may be determined from the data in tables 41–44 if the dry-bulb temperature and relative humidity are known. Given the dry-bulb and wet-bulb temperatures, the relative humidity may be determined from any of the figures 151–153.

Air movement must not be used indiscriminately; there are certain precautions to be observed, particularly when velocities over 200 fpm are used. Objectionable drafts are created if relatively cool air is blown over workers at high velocity. A velocity of 200 fpm is frequently quoted as the maximum safe rate, but considerably higher velocities can be used if the air has little cooling effect. A rate of 500 fpm was found to be unobjectionable in one industry,[153] and it is known that as much as 700 fpm can be used with impunity under certain conditions.

It was stated earlier that, for ordinary temperatures, maximum cooling at any velocity is obtained with saturated air. Let us see by example how this principle may be used to advantage in decreasing the effective temperature of the air blown over a worker. Assume a condition of 110° dry-bulb, 85° wet-bulb, and 300 fpm air movement. From figure 152 it is found that the effective temperature with moving air is 89° and with still air 91°; the cooling effect produced by the air movement alone under these conditions is only 2° ET. By passing this air through a humidifier in which the wet-bulb temperature remains unchanged, the dry-bulb temperature is reduced to 85°, and the effective temperatures with and without air movement are 79½ and 85°, respectively. Hence, the total reduction in effective temperature accomplished by humidification and air movement is 91 − 79½ or 11½°. It is evident, therefore, that humidification and air movement are useful measures for cooling workers in hot atmospheres.

Examples of the practical application of air movement with and without humidification to solve unbearable temperature conditions in a few industries follow:

1. *Mining Industry.* Sayers and Harrington[154] noted rises in the body temperatures of miners to as much as 103° when working in humid metal mines where the air was essentially still, the tempera-

TABLE 41

Effective Temperature of Air at 50 fpm under Different Conditions of Dry-Bulb and Humidity

Dry-Bulb Temperature (degrees F)	*Effective Temperature for Relative Humidity of*				
	20%	40%	60%	80%	100%
40	31.8	31.5	31.3	31.2	31.0
45	36.0	36.2	36.5	36.8	37.2
50	41.4	41.6	42.0	42.6	43.4
55	46.2	46.8	47.6	48.5	49.5
60	50.9	52.0	53.0	54.1	55.4
65	55.1	56.3	57.8	59.4	61.2
70	59.3	61.0	62.9	64.9	67.1
75	63.1	65.2	67.6	69.9	72.8
80	66.8	69.4	72.1	75.0	78.6
85	70.2	73.3	76.6	80.0	84.2
90	73.7	77.1	80.8	84.8	89.4
95	76.6	80.6	85.0	89.6	94.8
100	79.8	84.2	89.2	94.6	100.0
105	82.6	87.9	93.6	99.5	105.2
110	85.3	91.6	97.9	104.3	110.7
115	88.2	95.0	102.3	109.3	116.4
120	91.0	98.6	106.7	114.5	

TABLE 42

Effective Temperature of Air at 100 fpm under Different Conditions of Dry-Bulb and Humidity

Dry-Bulb Temperature (degrees F)	*Effective Temperature for Relative Humidity of*				
	20%	40%	60%	80%	100%
40					
45	31.9	31.6	31.3	31.0	30.7
50	37.1	37.1	37.2	37.2	37.3
55	42.7	43.0	43.2	43.7	44.8
60	48.0	48.6	49.3	50.0	51.0
65	52.8	53.9	55.0	56.2	57.7
70	57.6	58.8	60.5	62.3	64.3
75	61.8	63.6	65.8	67.9	70.7
80	65.8	68.0	70.7	73.6	77.1
85	69.6	72.2	75.4	79.0	83.4
90	73.0	76.1	79.9	84.0	89.0
95	76.2	80.0	84.1	89.0	94.5
100	79.3	83.8	88.6	94.2	100.0
105	82.3	87.3	93.0	99.3	105.5
110	85.2	90.9	97.7	104.5	111.6
115	88.0	94.6	102.3	109.9	
120	90.9	98.4	106.9	115.8	

TABLE 43

EFFECTIVE TEMPERATURE OF AIR AT 200 FPM UNDER DIFFERENT CONDITIONS OF DRY-BULB AND HUMIDITY

Dry-Bulb Temperature (degrees F)	*Effective Temperature for Relative Humidity of*				
	20%	40%	60%	80%	100%
40					
45					
50	32.0	31.5	30.8	30.0	
55	38.0	37.7	37.4	37.1	36.7
60	44.0	44.1	44.2	44.3	44.4
65	49.5	50.0	50.7	51.3	52.2
70	54.8	55.9	56.8	58.0	59.9
75	59.8	61.1	62.7	64.9	67.3
80	64.2	66.0	68.3	70.9	74.5
85	68.4	70.8	73.5	76.9	81.5
90	72.2	75.1	78.4	82.7	88.0
95	75.7	79.1	83.1	88.2	94.0
100	79.0	83.1	87.8	93.8	100.0
105	82.2	86.9	92.4	99.3	106.4
110	85.0	90.5	97.4	105.1	113.9
115	87.8	94.4	102.4	111.3	
120	90.7	98.1	107.8	118.4	

TABLE 44

EFFECTIVE TEMPERATURE OF AIR AT 700 FPM UNDER DIFFERENT CONDITIONS OF DRY-BULB AND HUMIDITY

Dry-Bulb Temperature (degrees F)	*Effective Temperature for Relative Humidity of*				
	20%	40%	60%	80%	100%
40					
45					
50					
55	30.0				
60	36.0	34.3	32.4		
65	42.0	41.2	39.8	38.0	36.5
70	48.0	47.8	47.0	46.4	46.0
75	53.3	53.8	54.2	54.6	55.4
80	58.7	59.6	60.5	62.0	64.0
85	63.4	65.0	66.7	69.2	72.9
90	68.2	70.4	72.3	76.2	81.9
95	73.0	75.2	78.4	83.3	91.4
100	77.7	80.2	84.2	90.8	100.8
105	81.5	84.9	89.9	98.6	110.8
110	84.7	89.3	96.2	108.3	
115	87.4	93.4	103.3		
120	90.0	97.8	111.1		

ture varied between 80 and 90° F and the humidity reached 95% at times. After the air was circulated at the rate of 400 to 500 fpm, there was no increase in body temperature, and the workers were much more comfortable. Reference to figure 153 will show that the effective temperature was reduced from about 88° to 81½°, a rather comfortable condition for men accustomed to working in mines.

2. *Steel Industry.* In a Pittsburgh steel mill there existed a condition in summer where the air temperatures were in the order of 112° F dry-bulb and 86° wet-bulb, and the natural air movement was about 100 fpm. Production was observed to be less in summer than in winter, and management decided to attempt to improve the temperature conditions. By saturating the air at the wet-bulb temperature of 86° F and blowing it on the workers with a velocity of 400 fpm, the effective temperature was decreased from 91° to 80°, a satisfactory working temperature for steel mills. Had the air movement rate alone been increased to 500 fpm the drop in effective temperature would have been only 1°.

Other similar and well-chosen examples have been reported recently (see reference 153). In some of these, the industry affected was previously in the habit of shutting down during the very hot summer days; a condition which was no longer necessary after the improvements had been made. The improvements consisted largely of increasing the rate of air movement, decreasing its effective temperature, and reducing the amount of heat transferred to the worker by the process or by nearby heated objects.

The operators of overhead cranes in hot industries are exposed to such high air temperatures, frequently in addition to smoke and irritating gases, that it is often necessary to limit their work to alternating short on and off periods. Air-conditioned crane cabs are now available commercially which provide the operator with comfortable atmospheric conditions without sacrificing visibility.[155, 156] Where it is impracticable to install or use air-conditioned cabs, the operator may be kept comfortable by supplying properly conditioned air to a special uniform which he wears.[157] The conditioned air enters the uniform at a convenient place, such as the center of the back, and is wasted at the neck and ankles. Equipment of this type will serve also for other hot operations such as cleaning out hot furnaces where the worker cannot be cooled by other methods.

In some departments of the textile industry, very high humidities are necessary to obtain the best operating conditions. This seldom results in any serious health hazards to the workers if the necessary

precautions are observed before entering and leaving the plant. If the humidity is high enough to result in damp clothing at the end of the shift, a complete change of clothing and suitable locker and shower rooms should be provided so that all the workers in high humidity may change in a dry place from their street clothes to work clothes at the beginning of the shift and take a shower and change back to the street clothes at the close of each shift.

In those industries, such as the manufacture of instruments and percussion elements, where a constant year-round temperature of about 70° F is maintained, the employees are exposed during warm weather to the sudden shock of a relatively cold atmosphere when entering the conditioned space and to that of a hot atmosphere when leaving the plant. In such cases the employees should be provided with suitable clothing to keep them warm during their stay in the conditioned room. During the summer the employees should be granted near the close of the shift a short period, depending upon the temperature difference between the inside and outside air, to relax in the warm atmosphere and acclimate themselves before rushing to get home as is the case at the close of the work shift. Also, if the temperature difference is considerable, a slight increase in activity directly before leaving the cool room is advisable.

Air conditioning in summer has proved to be a good investment in those industries where the workers are exposed to substances which cause dermatitis. Keeping the working environment cool reduces perspiration and eliminates much face wiping with grossly contaminated handkerchiefs or garment sleeves, thus reducing the contact between the harmful substance and the skin.

Heating, Ventilating, and Air Conditioning for Efficiency and Comfort. This section will be devoted to a summary of the considerations involved in ventilating or air conditioning work spaces such as office buildings and small instrument assembly or inspection lines in which the major source of atmospheric contamination is the occupants. For such spaces the heating and ventilating or the air-conditioning equipment is designed to (1) produce a comfortable temperature for the occupants by heating and humidifying in the cold season and by cooling and dehumidifying in the warm season, and (2) maintain proper air quality by supplying sufficient outside air to keep the odors at an unobjectionable level and to keep the chemical composition of the air within close limits.

The air conditions to be obtained in work spaces included in this

group are best illustrated by abstracting and summarizing pertinent parts of the ASHVE ventilation standards.[158]

The *temperature* and *humidity* of the air in such occupied spaces, and in which the only source of contamination is the occupant, should be maintained at all times during occupancy as follows: effective temperature (36 in. above the floor) between 64° and 69° when heating or humidification is required, and between 69° and 73° when cooling or dehumidification is required and humidity between 30% and 60%.

The air (*quality*) in such occupied spaces should at all times be free from toxic, unhealthful, or disagreeable gases and fumes and should be relatively free from odors and dust.

The air in such occupied spaces should at all times be in constant *motion* sufficient to maintain a reasonable uniformity of temperature and humidity but not such as to cause objectionable drafts in any occupied portion of such spaces. The air motion in such occupied spaces, and in which the only source of contamination is the occupant, should have a velocity of not more than 50 fpm when measured 36 in. above the floor.

The air in all rooms and enclosed spaces should be *distributed* with reasonable uniformity, and the variation in the carbon dioxide content of the air should be taken as a measure of such distribution. The carbon dioxide concentration when measured 36 in. above the floor should not exceed 100 ppm.

The *quantity* of air used to ventilate the space during occupancy should always be sufficient to maintain the standards of air temperature, air quality, air motion, and air distribution stipulated above. Not less than 10 cfm per occupant of the total air circulated to meet the foregoing requirements should be taken from an outdoor source.

In addition to the requirements set forth in the ASHVE ventilation standards, the following are applicable to spaces in which the heating, ventilating, and air-conditioning requirements are based on the conditions required or produced by the occupants: [152, 159, 160, 161]

1. The comfort temperature in air-conditioned spaces increases as the outdoor temperature increases. In table 45 are given the recommended indoor temperatures for various outdoor temperatures.

2. The quantity of outdoor air required to control body odors satisfactorily decreases as the volume space per occupant increases.[2, 162, 163] Recommended rates of outdoor air supply for different volumes of space per occupant are given in table 46. These values must be increased as the severity of labor increases.

TABLE 45

DESIRABLE INDOOR CONDITIONS IN SUMMER FOR DIFFERENT OUTDOOR TEMPERATURES

Outdoor Temperature, Dry Bulb (degrees F)	*Indoor Temperature (degrees F)*	
	Effective	Dry Bulb (approximately)
100	75	82
95	74	81
90	73	80
85	72	79
80	71	77

TABLE 46

MINIMUM OUTDOOR REQUIREMENTS TO REMOVE OBJECTIONABLE BODY ODORS FOR SEDENTARY ADULT WORKERS

Air Space per Person (cubic feet)	*Outdoor Air Supply per Occupant (cubic feet per minute)*
100	25
200	16
300	12
500	7

3. There have been much speculation and many reports on the influence of air conditioning upon the incidence of respiratory illness of the occupants.[164, 165, 166, 167, 168, 169] The claims run anywhere from "substantial reduction" to "no effect." On the basis of these differences in reported results it is impossible at present to say whether air conditioning has or does not have a favorable influence on the incidence of respiratory illnesses of the affected persons. Certainly the data at hand do not give the engineer any ammunition to sell air conditioning on the basis of fewer respiratory illnesses; the logical and factual basis still remains the increased efficiency of the workers and reduction in accidents as shown earlier in this chapter.

CHAPTER XIV

RADIANT ENERGY

The radiant energy occurring in industry today which is of concern to industrial health engineers may be classified into four groups for convenient discussion.

1. Radiant energy in the form of heat (infrared rays) from hot objects in the "hot industries."
2. Radiant energy in the form of gamma rays from radium or radioactive substances.
3. Radiant energy in the form of ultraviolet rays produced in electric arc welding.
4. Radiant energy in the form of X rays from all X-ray equipment.

Radiant Energy in the Form of Heat. In hot industries, such as iron, steel, glass, and foundry, workers are frequently subjected to heat of such intensity that they are obliged to work only intermittently for short periods or at a very low efficiency.[147, 170, 171] In addition to their internal heat production, they may gain heat by conduction and convection from the air or by radiation from nearby hot objects. Under such conditions the only means of eliminating the heat is by evaporation of perspiration. If the air temperature is not above that of the body, heat is eliminated both by evaporation of perspiration and by conduction from the body to the air. How workers in hot industries may be cooled by proper air conditions was explained in Chapter XIII; this section will be devoted to the various aspects of radiant energy and its control.

It has been reported that exposure to excessively hot conditions may produce heat cramps, skin erythema, cataracts, and subtle physiological derangement affecting the leucocyte count of the blood and other factors dealing with man's mechanism of defense against infection.[172, 173] A maximum allowable concentration for infrared rays has not been established and probably will not be since the effect on the worker is dependent on the other atmospheric condi-

tions also. In Chapter XIII several maxima recommended effective temperatures for different rates of work were suggested, but these are based largely on atmospheric conditions *other than* radiant heat.

Even though much can be accomplished by proper ventilation and air conditioning to cool the workers at hot operations, the primary control measure should be reduction of the amount of heat radiated by hot objects and received by the workers. By decreasing the heat radiated from primary heat sources, not only is the heat received by the worker from this source decreased, but the temperature of the atmosphere and of other objects is reduced also, resulting in a further improvement of the employee's working environment. In some instances, for example, the worker receives no direct heat rays from the primary heat source but does receive reflected or reradiated heat from several other objects which are heated by the primary source. The secondary heat sources, those objects which receive heat from the primary source, contribute further to the worker cooling problem in that they dissipate some of their heat to the air as it passes over them thereby increasing unnecessarily the temperature of the general ventilation air which is intended to cool the worker. Even if "spot cooling" or "air douches" are used for the individual worker whose exposure is severe, improper shielding of the primary heat source permits the ventilating ducts or pipes to be heated with the result that the cooling air for the "air douches" is heated needlessly.

It is obvious, therefore, that in attempting to reduce the heat reaching the workers in hot industries emphasis should be placed on shielding or insulating the primary heat source not only as regards the worker but also as regards all other objects; in other words, total enclosure from the direct exposure viewpoint. This can seldom be done, but the primary effort should be directed toward enclosing or insulating the primary source as completely as possible and cooling the insulating or shielding materials by means of water or air so that the amount of heat they contribute to the worker, or the worker's immediate atmosphere, is at a minimum. The ventilation or worker-cooling air can be used effectively for this purpose if arrangements are such that the air passes over the worker first and then over the shields or secondary heat sources, rather than vice versa.

Little work in this direction appears to have been reported in the literature. It is hoped that some fundamental research may be done

on it in the near future so that the industrial hygiene and plant engineers who face problems of this nature may have some factual basis to follow rather than theories, assumptions, or guesswork.

Gamma-Ray Radiation. Danger from gamma-ray radiation exists wherever radium or radioactive compounds are handled or stored. The effects of continued exposure to low radiation intensities are not well known. The commonly accepted maximum allowable safe concentration for gamma-ray radiation is 0.1 roentgen per 8-hour day. Overexposure of the entire body may cause a reduction in vitality, lassitude, frequent headaches, anemia, and possibly leukemia.[116] Extreme overexposure of some part of the body may result in radium burns. It must be borne in mind that only the gamma rays are covered in this chapter. Control of the hazard from ingestion or inhalation of solid radioactive compound and from inhalation of the radon gas liberated by radioactive materials was discussed in Chapter X.

Exposure to excessive amounts of gamma rays may be prevented by one or a combination of four methods.[115, 116, 172, 174, 175]

1. Store, handle, or use the smallest possible amounts of the radioactive compound.
2. Keep workers as far away from the compound as possible.
3. Use protective barriers such as lead.
4. Limit exposure time to a minimum.

These control measures need little amplification. The interrelationship of the first three control measures to accomplish safety on the basis of continued 8-hour daily exposure is given by the following equation:

$$D = KL\sqrt{R} \tag{41}$$

where D = required distance in centimeters between worker and radium for different amounts of radium and different thicknesses of protective lead sheeting.

K = a constant varying with the thickness of the lead sheet as given in table 47.

L = thickness in centimeters of protective lead sheeting.

R = quantity of radium in milligrams.

Similar data are given in table 48. For intermittent short exposures the quantity of radium, thickness of lead, or distance from the compound may be increased proportionately. On the other hand,

TABLE 47

VALUES OF K FOR DIFFERENT VALUES OF L IN EQUATION 41

Thickness in Centimeters of Protective Lead Barrier	*Value of K*
0.1	251
0.5	44.7
1	18.5
2	7.25
3	3.73
4	2.00
5	1.27
6	0.83
8	0.39
10	0.181
12	0.108
14	0.0583
16	0.0345
18	0.0227
20	0.0150

TABLE 48

INTERRELATIONSHIP BETWEEN THE QUANTITY OF RADIUM, THE THICKNESS OF LEAD PROTECTION, AND THE DISTANCE FROM THE SOURCE TO RENDER THE CONDITION SAFE FOR 8-HOUR DAILY EXPOSURES

Thickness of Lead Protection in Centimeters	Quantity of Radium in Milligrams												
	0.1	0.5	1.0	5	10	50	100	500	1000	5000	10,000	50,000	100,000
	Required Distance in Centimeters from Source for Safety												
0.1	8	18	25	55	80	180	275	550	800				
0.5	7	16	22	50	70	160	230	500	725				
1	6	13	19	45	60	130	190	425	600				
2	5	10	15	35	45	110	150	325	475	1000			
3	4	8	12	25	35	80	120	275	350	800			
4		6	8	18	25	55	80	190	275	550	800		
5			7	15	20	45	65	150	210	450	650		
6				12	16	35	50	125	160	350	500		
8					10	25	30	70	100	250	325	700	
10						15	18	40	60	150	200	400	600
12							15	30	45	90	130	300	400
14								20	30	60	85	200	300
16									20	40	55	140	175
18										30	45	90	150
20										25	30	70	95

if the stipulated conditions given in the table are not met, the time of exposure should be decreased proportionately.

At the time of this writing few data have yet been reported on the control measures employed in the "atomic" industry. It is hoped that the methods employed so effectively in this potentially very hazardous industry may suggest new approaches for the general problem of radiant energy control.[176]

Ultraviolet Radiation. The most common potential exposure to ultraviolet rays at industrial operations is in electric arc welding. Exposure to excessive amounts of ultraviolet light may cause conjunctivitis, corneal ulcers, or iritis.[172]

Controlling the health hazard from ultraviolet radiation in welding is largely an indirect procedure, protecting the welder and other nearby workers. Two kinds of protection are needed: one for the exposed portions of the body and the other for the eyes.

The risk from burns of the unprotected skin, such as the arms, neck, ears, or side of the face, is not great, but almost every industry in which much electric welding is done has had one or more such experiences. The burn from welding arcs can be very painful and is comparable to severe sunburn. It can be prevented effectively by means of gloves, welding helmets, and other suitable guards.

To protect the eyes of the welder and his helper or other workers in the immediate vicinity suitable glasses, goggles, or welding helmets should be worn. There is available commercially a large variety of special lenses or glasses which are designed to protect the eyes against different intensities of ultraviolet. The density of the glass, or intensity of the ultraviolet which it is intended to protect against, is indicated by shade number. The proper shade number for different kinds of welding operations or for different exposures to the harmful rays is given in table 49.[177]

Goggles or helmets are usually worn by the welders and the other workers in the immediate vicinity of the welding operations. However, the casual passerby, such as the foreman, as well as the nearby welder who has raised his helmet momentarily, is without protection from "flashes" from neighboring welders. Accidental exposures of this type may be avoided by the use of suitable screens such as sheet metal, board, or canvas. All permanent welding stations should be inclosed by such screens so staggered as to permit good air movement in and out but to prevent direct exposure to the welding arc from any outside point. Portable screens should be used wherever practicable when welding in temporary locations.

X-Ray Radiations. Potential exposure to X-ray radiation exists wherever X-ray equipment is used. However, industrial health engineers generally are interested only in the conditions created by the use of such equipment in industry, largely quality-control inspections. Many plant hospitals have X-ray machines which warrant investigation, but if properly operated and maintained they usually do not constitute an important hazard. Even the quality-control inspection equipment, which may produce as much as 2,000,000 volts, if installed by a capable engineer, seldom creates an important exposure hazard to the nearby workers. Nevertheless. machines of this type should be checked carefully for stray radiation when they are first placed in operation and periodically thereafter. The best way to determine the adequacy of the control features is to measure the stray radiation at some of the workers and at all locations where it is felt that the protective barriers are not adequate.

TABLE 49

EYE PROTECTION RECOMMENDED FOR WELDING

Operation	*Type of Protection and Shade Number of Lenses or Glass*
Production welding at a permanent location	Permanent shield with proper density light filter, helmet or hand shield with proper density light filter, or goggles with proper density lenses
Working in the vicinity of a welding operation	Goggles or spectacles with No. 3 or 4 shade lenses
Light gas cutting and welding and light electric spot welding	Goggles or spectacles with No. 5 shade lenses
Gas cutting, medium gas welding, and arc welding up to 30 amp	Helmet, shield, or goggles with No. 6 shade lenses or filter glass
Heavy gas welding, arc cutting, and welding between 30 and 75 amp	Helmet, shield, or in some cases goggles with No. 8 shade filter glass
Arc welding and cutting between 75 and 200 amp	Helmet or shield with No. 10 shade filter glass
Arc welding and cutting between 200 and 400 amp	Helmet or shield with No. 12 shade filter glass
Arc welding and cutting above 400 amp	Helmet or shield with No. 14 shade filter glass

The maximum allowable safe concentration for X-ray radiation is 0.1 roentgen per 8-hour day. Overdosage may cause changes in the hair and nails, keratosis, ulceration, and malignant degeneration of the skin, and, perhaps, sterility, anèmia, and leukemia.[178]

Protection is needed not only from the direct radiation but also

from scattered or reflected radiation. Since the intensity of the radiant energy decreases as the square of the distance from the source, distance alone provides good protection, but this safeguard by itself is seldom adequate. The beam of high voltage machines should be directed at the ground or at an outside wall on the exterior side of which few or no people are located. Barriers of lead or concrete or both are usually employed for protection and are very effective if properly dimensioned and constructed. It is reported that lead causes less scattering than concrete and in addition tends to harden the rays.[179] Since concrete is more effective against the hard than the soft rays, the combination of lead on the inside and concrete on the outside is particularly effective. It has been the author's experience in recent years that industrial X-ray equipment of very high voltage can be so constructed as to control the potential exposure hazard very effectively.

CHAPTER XV

INDUSTRIAL ILLUMINATION *

Illumination is a factor of primary importance which affects the environment in every industrial establishment. The beneficial effects of good illumination, both natural and artificial, have been established in extensive tests over many years. The advantages to industry are many; some of the more important ones are

1. Greater accuracy of workmanship, resulting in an improved quality of product with less spoilage and rework.[180, 181]
2. Increased production and decreased costs.[182, 183]
3. Better utilization of floor space.[184]
4. Greater ease of seeing, especially among the older and experienced employees, thus making them more efficient and permitting industry to continue utilizing their experience.
5. Less eyestrain among employees.[185]
6. Improved morale among employees, resulting in decreased labor turnover.
7. Facilitates housekeeping, sanitation, cleanliness, and neatness in the plant; a well-lighted plant is seldom a dirty one, and filth or rubbish do not accumulate in well-lighted corners.
8. Better supervision of workers; constructive supervision requires good illumination so that the foreman can easily detect the faulty or inefficient actions of the workers.
9. Greater safety.[186]

FACTORS OF GOOD ILLUMINATION

There are many factors involved in good illumination. Because of this, lighting installations should be designed by a competent illuminating engineer. However, those who live with the lighting and those who must justify its cost should be acquainted with some of the factors to be considered. These can be summed up under the headings of quality, which includes the color of light, its direction, diffusion, absence of glare, etc.; and quantity, or the amount of illumination.

* Adapted from "American Recommended Practice of Industrial Lighting," published by the Illuminating Engineering Society.

Quality of Lighting. The quality of the lighting [187] whether natural or artificial is highly important in providing good seeing conditions. Glare, diffusion, direction, and distribution have significant effects on visibility and the ability to see easily, accurately, and quickly.

Glare [188, 189, 190] may be defined as any brightness within the field of vision of such character as to cause discomfort, annoyance, interference with vision, or eye fatigue. It is one of the most common and serious faults of lighting installations.

Glare is objectionable because (1) when continued it tends to injure the eye and disturb the nervous system; (2) it causes discomfort and fatigue and thus reduces the efficiency of the workman; and (3) it interferes with, and often prevents, clear vision and thus reduces efficiency and in many cases increases the risk of accidents or injury to the workmen.

There are two common forms of glare, "direct" and "reflected." Direct glare is caused by excessive brightness or brightness contrast within the visual field; that is, unshielded lamps or high-brightness surfaces of fixtures.

To reduce direct glare from the artificial lighting, direct general-lighting luminaires should be mounted at a sufficient height to keep them well above the normal line of vision. They should be properly designed to limit both the brightness and the quantity of light emitted in directions directly below the horizontal since such light is well within the normal field of view and interferes with vision. High brightness contrasts should be avoided. For example, an unshielded lamp viewed against the low brightness of a dark ceiling may be very glaring, similarly, a bright window seen against darker surrounding walls.

Supplementary lighting sources should be carefully designed so that the light is confined to the immediate working area. Failure to observe this precaution may cause extreme annoyance not only to the workman using the source but to others in the vicinity. Care should also be exercised to prevent excessive brightness contrasts between the work and the surroundings.

Reflected glare, as its name implies, is caused by high brightnesses, images, or brightness contrasts reflected from ceilings, walls, desk tops, or other surfaces within the visual field, such as materials and machines. These brightnesses are accentuated when the surfaces are glossy or specular in character, such as highly polished machine parts, smooth-finished surfaces, varnished table tops, or other highly

reflective surfaces. Reflected glare is frequently more annoying than direct glare because it is so close to the line of vision that the eye cannot avoid it. The effect of reflected glare for a given image brightness is reduced with higher levels of general illumination because of the reduction in contrast.

Some directional and shadow effects are desirable in general illumination for accentuating the depth and form of solid objects, but harsh shadows should be avoided. Shadows are softer and less pronounced when *diffusing* units and units having a wide *distribution* of light are used, since then the object is illuminated from many sources. Alternate light and dark areas in strong contrast are undesirable because the eye has difficulty in adjusting itself for the two illuminations and seeing becomes tiring. For this reason, purely local lighting restricted to a small work area is unsatisfactory unless there is sufficient general illumination in the room.

Clearly defined shadows, without excessive contrast, are a distinct aid to sight in certain types of operations, such as engraving on polished surfaces, scribed layout work, and textile inspection. When such shadow effect is indicated, it is best obtained by supplementary directional light combined with diffused illumination of ample intensity.

Much attention has been given to measurement of foot-candles on the horizontal plane. Actually many of the seeing tasks in industry are on vertical or nearly vertical surfaces. Hence the amount and the distribution of light on vertical surfaces may be of great importance.

It appears that with equal foot-candles of illumination, variations in *color quality* of light have little or no effect upon clearness and quickness of seeing.[191, 192] However, in certain industries color discrimination is highly important, and light sources which provide lighting that will enable the matching to be carried on most accurately should be used. This again is a matter in which the illuminating engineer should be consulted.

Light-colored surfaces serve several purposes in the factory. They are of particular value in providing a high utilization of light because they reflect more light toward the working areas. Also, bright window areas and artificial light sources are less uncomfortable to the eye when viewed against light backgrounds.

Many progressive concerns are painting all of their machinery with light-tinted durable paints. This provides an increased amount

of light which is reflected to the otherwise shadowed sections of the machine. Some manufacturers paint stationary and moving parts of machines different colors to prevent accidents by thus aiding perception.

Quantity of Light. The desirable quantity of light for any particular installation depends primarily upon the work which is being done. The degree of accuracy, the fineness of detail to be observed, the color and reflectivity of the work as well as of the immediate surroundings materially affect the distribution of brightness which will produce maximum seeing conditions. Investigations in the field and laboratory have proved that as the illumination on the task is increased, the ease, speed, and accuracy with which the task can be accomplished are increased. These tests have not yet established an upper limit, but the harmful effects of low-foot-candle values are well known.[182]

With the aid of a suitable visibility meter [193] it is now possible to determine the relative ease of seeing two objects. It is a most valuable instrument in the hands of one trained in its use and familiar with the operation being checked. It is possible to measure quantity of light quickly and reasonably accurately with any of the various meters employing light-sensitive cells. These instruments are direct reading and simple, but they should be calibrated at frequent intervals. It is highly important that the measurement be made at the point and in the plane in which the seeing task is performed, whether it be horizontal, vertical, or at some intermediate angle. If lighting is a combination of natural and artificial illumination, that part due to natural light should be measured separately from that due to the artificial light, since in many cases at one hour of the day there is a great amount of natural light while at a different time it may fail entirely. Brightness measurements hitherto difficult of accomplishment are now easily made with a brightness meter, such as the Luckiesh-Taylor, Luckiesh-Holladay, and Macbeth.

RECOMMENDED MINIMUM STANDARDS OF ILLUMINATION

The majority of the recommended values of illumination in table 50 refer to the general lighting or lighting throughout the total area involved as measured on a horizontal plane 30 in. above the floor. Sometimes where an illumination of more than 50 foot-candles is necessary it may be obtained by a combination of general lighting

plus supplementary lighting at the point of work. An asterisk after the foot-candle figure denotes that the combination of general and supplementary illumination is desirable.

The Illuminating Engineering Society has been studying the illumination needs of specific industries in recent years.[194] Wherever reports of these industries have been completed, the foot-candles included in table 50 are taken from that report. In other cases, the values are based upon current good practice. These reports should be consulted for detailed lighting specifications for manufacturing processes.

Attention is called to the fact that the values given are minimum operating values; that is, they apply to measurements of the lighting system in use, not simply when the lamps and reflectors are new and clean, and in almost every instance higher values may be used with greater benefit. Where safety goggles are worn, the light reaching the eye is likely to be materially reduced, and the general level of lighting should, therefore, be increased accordingly in such locations.

MAINTENANCE OF ILLUMINATION

The proper and adequate maintenance of equipment is essential for both natural and artificial lighting. Systems which are adequate when first installed will soon deteriorate unless properly maintained. A regular, definite system of maintenance should be established to insure that skylights, side windows, lamps, and accessories are at all times kept clean, in proper adjustment, and in good repair. The recommended method of establishing a suitable maintenance schedule for the cleaning of lighting equipment is to check the illumination periodically with a light meter. When the illumination has decreased to 75% of its initial value, the lighting equipment should be washed with a detergent (without free alkali) and warm water. Frequently a group-replacement plan of relamping can be established to coincide with the cleaning period with a resultant saving in maintenance costs.

Means should be provided for easy access to all lighting units. Walls and ceilings should be repainted, preferably in light tones, at regular intervals. With indirect lighting systems, it is essential that the ceiling be kept clean since the illumination comes from the ceiling. It should be remembered that the illumination requirements

TABLE 50

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Aisles, stairways, passageways	5
Assembly	
Rough	10
Medium	20
Fine	*B* *
Extra fine	*A* *
Automobile manufacturing	
Assembly line	*B* *
Frame assembly	15
Body manufacturing	
Parts	20
Assembly	20
Finishing, inspecting	*A* *
Bakeries	20
Book binding	
Folding, assembling, pasting, etc.	10
Cutting, punching, stitching	20
Embossing	20
Breweries	
Brew house	5
Boiling, keg washing, filling	10
Bottling	15
Candy making	
Box department	20
Chocolate department	
Husking, winnowing, fat extraction, crushing and refining, feeding	10
Bean cleaning and sorting, dipping, packing, wrapping	20
Milling	*C* *
Cream making	
Mixing, cooking, molding	20
Gum drops, jellied forms	20
Hand decorating	*C* *
Hard candy	
Mixing, cooking, molding	20
Die cutting and sorting	*C* *
Kiss making, wrapping	*C* *
Canning, preserving	20

* See reference footnotes at end of table.

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Chemical works	
Hand furnaces, boiling tanks, stationary driers, stationary and gravity crystallizers	5
Mechanical furnaces, generators and stills, mechanical driers, evaporators, filtration, mechanical crystallizers, bleaching	10
Tanks for cooking, extractors, percolators, nitrators, electrolytic cells	15
Clay products, cements	
Grinding, filter presses, kiln rooms	5
Molding, pressing, cleaning, trimming	10
Enameling	15
Color and glazing	20
Cleaning and pressing industry	
Checking, sorting	20
Dry and wet cleaning, steaming	10
Inspection, spotting	*A* *
Pressing	
Machine	20
Hand	*C* *
Receiving, shipping	10
Repair, alteration	*C* *
Cloth products	
Cutting, inspecting, sewing	
Light goods	20
Dark goods	*A* *
Pressing, cloth treating (oil cloth, etc.)	
Light goods	10
Dark goods	20
Coal tipples, cleaning plants	
Breaking, screening, cleaning	10
Picking	*A* *
Construction—indoor	
General	10
Dairy products	20
Elevators—freight and passenger	10
Engraving	*A* *
Forge shops, welding	10
Foundries	
Charging floor, tumbling, cleaning, pouring, shaking out	5
Rough molding, core making	10
Fine molding, core making	20

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Garages—automobile	
Storage—live	10
Storage—dead	2
Repair department, washing	*C* *
Glass works	
Mix and furnace rooms, pressing and lehr, glass-blowing machines	10
Grinding, cutting glass to size, silvering	20
Fine grinding, polishing, beveling, etching, decorating	*C*,* *D* *
Inspection	*B*,* *D* *
Glove manufacturing	
Light goods	
Pressing, knitting, sorting	10
Cutting, stitching, trimming, inspecting	20
Dark goods	
Cutting, pressing, knitting, sorting	20
Stitching, trimming, inspection	*A* *
Hangars—aeroplane	
Storage—live	10
Repair department	*C* *
Hat manufacturing	
Dyeing, stiffening, braiding, cleaning, refining	
Light	10
Dark	20
Forming, sizing, pouncing, flanging, finishing, ironing	
Light	15
Dark	30
Sewing	
Light	20
Dark	*A* *
Ice making—engine and compressor room	10
Inspection	
Rough	10
Medium	20
Fine	*B* *
Extra fine	*A* *
Iron manufacturing, *see* Steel and iron manufacturing	
Jewelry and watch manufacturing	*A* *
Laundries	20
Leather manufacturing	
Vats	5

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Leather manufacturing (*Continued*)	
Cleaning, tanning, stretching	10
Cutting, fleshing, stuffing	20
Finishing, scarfing	30
Leather working	
Pressing, winding, glazing	
Light	10
Dark	20
Grading, matching, cutting, scarfing, sewing	
Light	20
Dark	*A* *
Locker rooms	5
Machine shops	
Rough bench and machine work	10
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	20
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing	*B* *
Extra-fine bench and machine work, grinding	
Fine work	*A* *
Meat packing	
Slaughtering	10
Cleaning, cutting, cooking, grinding, canning, packing	20
Milling—grain foods	
Cleaning, grinding, rolling	10
Baking or roasting	20
Flour grading	30
Offices	
Bookkeeping, typing, accounting	30
Business machines—power driven (transcribing, tabulating)	
Calculators, key punch, bookkeeping	*B* *
Conference room	
General meetings	10
Office activities, *see* Desk work	
Corridors, stairways	5
Desk work	
Intermittent reading and writing	20
Prolonged close work, computing, studying, designing, etc.	*C* *
Reading blueprints and plans	30

TABLE 50 (*Continued*)

RECOMMENDED MIMINUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Offices (*Continued*)	
Drafting	
Prolonged close work—art drafting and designing in detail	*C* *
Rough drawing and sketching	30
Filing, index references	20
Lobby	10
Mail sorting	20
Reception rooms	10
Stenographic work	
Prolonged reading shorthand notes	*C* *
Vault	10
Packing, boxing	10
Paint mixing	10
Paint shops	
Dipping, simple spraying, firing	10
Rubbing, ordinary hand painting and finishing—art, stencil, special spraying	20
Fine hand painting and finishing	*B* *
Extra-fine hand painting and finishing (automobile bodies, piano cases, etc.)	*A* *
Paper-box manufacturing	
Light	10
Dark	20
Storage	5
Paper manufacturing	
Beaters, grinding, calendering	10
Finishing, cutting, trimming, paper-making machines	20
Plating	10
Polishing, burnishing	15
Power plants, engine room, boilers	
Boilers, coal and ash handling, storage-battery rooms	5
Auxiliary equipment, oil switches, transformers	10
Engines, generators, blowers, compressors	15
Switchboards	*C* *
Printing industries	
Type foundries	
Matrix making, dressing type	*A* *
Font assembly—sorting	*B* *
Hand casting	*C* *
Machine casting	20

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Printing industries (*Continued*)	
Printing plants	
Presses	*C* *
Imposing stones	*A*,* *D* *
Proofreading	*A* *
Photography	
Dry plate and film	2000
Wet plate	3000
Printing on metal	2000
Electrotyping	
Molding, finishing, leveling molds, routing, trimming	*B* *
Blocking, tinning	*C* *
Electroplating, washing, backing	20
Photo engraving	
Etching, staging	20
Blocking	*C* *
Routing, finishing, proofing	*B* *
Tint laying	*A* *
Receiving, shipping	10
Rubber goods, mechanical	
Stock preparation	
Plasticating	20
Milling	20
Calendering	30
Branbury	20
Fabric preparation	
Stock cutting	30
Hose looms	30
Molded products	*B* *
Extruded products	30
Curing	*B* *
Inspection	*A* *
Boxing	20
Warehouse	5
Rubber tire and tube manufacturing	
Stock preparation	
Plasticating	20
Milling	20
Calendering	30
Branbury	20

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Rubber tire and tube manufacturing (*Continued*)	
Fabric preparation	
Stock cutting	30
Bead building	30
Tube tubing machines	20
Tread tubing machines	20
Tire building	
Solid tire	20
Pneumatic tire	50
Curing department	
Tube curing	*B* *
Casing curing	*B* *
Final inspection	
Tube	*B* *
Casing	*A* *
Wrapping	20
Warehouse	5
Sheet-metal works	
Miscellaneous machines, ordinary bench work	15
Punches, presses, shears, stamps, welders, spinning, medium bench work	20, *D* *
Tin-plate inspection	*B*,* *D* *
Shoe manufacturing (leather)	
Cutting and stitching	
Cutting tables	10
Marking, buttonholing, skiving, sorting, vamping, counting	
Light materials	20
Dark materials	*C* *
Stitching	
Light materials	*C* *
Dark materials	*B* *
Making, finishing	
Stitchers, nailers, sole layers, welt beaters and scarfers, trimmers, welters, lasters, edge setters, sluggers, randers wheelers, treers, cleaning, spraying, buffing, polishing, embossing	
Light materials	20
Dark materials	*C* *
Storage, packing, shipping	10
Shoe manufacturing (rubber)	
Washing, coating, mill-run compounding	10

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Shoe manufacturing (rubber) (*Continued*)	
Varnishing, vulcanizing, calendering, upper and sole cutting	*C* *
Sole rolling, lining, making and finishing processes	*C* *
Soap manufacturing	
Kettle houses, cutting, soap chip and powder	10
Stamping, wrapping and packing, filling and packing soap powder	20
Steel and iron manufacturing	
Billet, blooming, sheet bar, skelp and slabbing mills	5
Boiler room, power house, foundry and furnace rooms	5
Hot sheet and hot strip mills	10
Cold strip, pipe, rail, rod, tube, universal plate and wire drawing	10 †
Merchant and sheared-plate mills	15 †
Tin-plate mills	
Hot-strip-rolling and tinning-machine department	10
Cold strip rolling	15
Inspection	
Black plate	*C* *
Bloom and billet chipping	*C* *
Tin plate, other bright surfaces	*B*,* *D* *
Machine shops, maintenance department	
Repair shops	
Rough bench and machine work	10
Medium bench and machine work	20
Fine work—buffing, polishing, etc.	*B* *
Extra-fine work	*A* *
Blacksmith shop	10
Laboratories (chemical, physical)	15
Carpenter and pattern shop	20
Storage	2
Stone crushing, screening	
Belt conveyor tubes, main-line shafting spaces, chute rooms, inside of bins	5
Primary-breaker room, auxiliary breakers under bins	5
Screens	10
Storage-battery manufacturing	
Molding of grids	10
Store and stock rooms	
Rough bulky material	5
Medium or fine material requiring care	10

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Structural steel fabrication	10
Sugar grading	30
Testing	
Rough	10
Fine	20
Extra-fine instruments, scales, etc.	*A* *
Textile mills (cotton)	
Opening, mixing, picking, carding, drawing	10
Slubbing, roving, spinning	20
Spooling, warping on comb	20
Beaming, slashing on comb	
Grey goods	20
Denims	*B* *
Inspection	
Grey goods (hand turning)	*C* *
Denims (rapidly moving)	*A* *
Automatic tying-in, weaving	*B* *
Drawing-in by hand	*A* *
Silk and rayon manufacturing	
Soaking, fugitive tinting, conditioning or setting of twist	10
Winding, twisting, rewinding, coning, quilling, slashing	30
Warping (silk or cotton system)	
On creel, on running ends, on reel, on beam, on warp at beaming	*C* *
Drawing-in	
On heddles	*A* *
On reed	*A* *
Weaving	
On heddles and reeds	5
On warp back of harness	10
On woven cloth	30
Woolen	
Carding, picking, washing, combing	10
Twisting, dyeing	10
Drawing-in, warping	
Light goods	15
Dark goods	30
Weaving	
Light goods	15
Dark goods	30

TABLE 50 (*Continued*)

RECOMMENDED MINIMUM STANDARDS OF INDUSTRIAL ILLUMINATION

(The values given in the table represent recommended order of magnitude rather than exact illumination levels)

Industry or Operation	*Illumination in Foot-Candles (Measured on the Work)*
Textile mills, woolen (*Continued*)	
Knitting machines	20
Tobacco products	
Drying, stripping, general	10
Grading, sorting	*A* *
Toilets, wash rooms	5
Upholstering automobile, coach furniture	20
Warehouse	5
Welding	30
Woodworking	
Rough sawing and bench work	10
Sizing, planing, rough sanding, medium machine and bench work, gluing, veneering, cooperage	20
Fine bench and machine work, fine sanding, finishing	*C* *

* Lighting recommendations for the more difficult seeing tasks, as indicated by *A*, *B*, *C*, and *D* in the foregoing table, are given in groups *A*, *B*, *C*, and *D* following.

Group *A*

These seeing tasks involve (*a*) the discrimination of extremely fine detail under conditions of (*b*) extremely poor contrast (*c*) for long periods of time. To meet these requirements, illumination levels above 100 foot-candles are recommended.

To provide illumination of this order a combination of at least 20 foot-candles of general lighting plus specialized supplementary lighting is necessary. The design and installation of the combination systems must not only provide a sufficient amount of light but must also provide the proper direction of light, diffusion, eye protection, and insofar as possible must eliminate direct and reflected glare as well as objectionable shadows.

Group *B*

This group of visual tasks involves (*a*) the discrimination of fine detail under conditions of (*b*) a fair degree of contrast (*c*) for long periods of time. Illumination levels from 50 to 100 foot-candles are required.

To provide illumination of this order a combination of 10 to 20 foot-candles of general lighting plus specialized supplementary lighting is necessary. The design and installation of the combination systems must not only provide a sufficient amount of light but must also provide the proper direction of light diffusion, eye protection, and insofar as possible must eliminate direct and reflected glare as well as objectionable shadows.

Group *C*

The seeing tasks in this group involve (*a*) the discrimination of moderately fine

given in the table apply to the lighting equipment under average operating conditions, not simply when new and clean as first installed.

Figure 154 shows the very considerable loss in illumination which results from the collection of dirt on lamps and lighting units. To insure that a given illumination will be maintained even where conditions are favorable, it is necessary to design the system to give initially at least 25% more light than the required minimum. In locations where the dirt will collect rapidly and where adequate maintenance is not provided, the initial value should be at least 50% above the minimum requirement. It is evident from a study of the figure that without adequate maintenance even this allowance may prove insufficient.

NATURAL LIGHTING

Factory owners in most industries are particularly interested in making the best possible use of their daylight facilities. The saw-tooth, monitor, or skylight windows of modern factory construction permit an adequate and more uniform daylight illumination of the entire floor area and are desirable when practicable. When rooms are illuminated through side windows it is often difficult or impos-

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detail under conditions of (*b*) better-than-average contrast (*c*) for intermittent periods of time.

The level of illumination required is of the order of 30 to 50 foot-candles, and in some instances it may be provided from a general lighting system. Often, however, it will be found more economical and yet equally satisfactory to provide from 10 to 20 foot-candles from the general system and the remainder from specialized supplementary lighting. The design and installation of the combination systems must not only provide a sufficient amount of light but must also provide the proper direction of light, diffusion, eye protection, and insofar as possible must eliminate direct and reflected glare as well as objectionable shadows.

Group *D*

The seeing tasks of this group require the discrimination of fine detail by utilizing (*a*) the reflected image of a luminous area or (*b*) the transmitted light from a luminous area.

The essential requirements are (1) that the luminous area shall be large enough to cover the surface which is being inspected, and (2) that the brightness be within the limits necessary to obtain comfortable contrast conditions. This involves the use of sources of large area and relatively low brightness in which the source brightness is the principal factor, rather than the foot-candles produced at a given point.

† In these areas many of the machines require one or more supplementary lighting units mounted on them in order to effectively direct light toward the working points.

sible to light satisfactorily all parts of the floor space and furnish adequate illumination to the workers without subjecting some of them to objectionable glare.

If only one wall contains windows, the width of the room perpendicular to this wall should be less than twice the height of the top of the windows above the floor; if windows are in two parallel walls, the width of the room between these walls should not exceed six times this window height. A monitor gives best results when

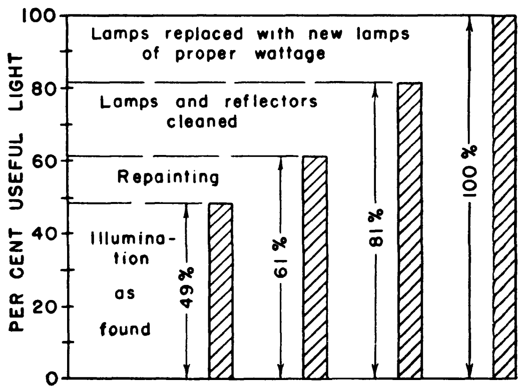

FIGURE 154. Influence of Various Conditions on Illumination

its width is about one-half the width of the building, and the height of the windows in the monitor is one-half of the monitor width. The height of the windows in saw-tooth construction should be at least one-third of the span. In general, single-story industrial buildings should have a window area of at least 30% of the floor area. Where it is practicable to do so, provision should be made for hose connections on the roof to facilitate washing the windows.

Reflection of daylight from surfaces outside a building has an important effect upon the lighting of a room. Faces of structures, walls of courts, and roofs of saw-tooth buildings should be finished in the lightest practicable colors and so maintained. The possibility of glare from such surfaces should, however, be considered.

Windows should be equipped with adjustable devices so that the illumination may be accommodated to changing exterior conditions. Window shades of light tones should be used, for at night they will reflect artificial light back into the room; shades, transmitting diffusely a large part of the natural light they receive, will generally

improve the daylight illumination. When practicable, shades should be mounted so as to permit the covering of any desired parts of the windows. Louvers or Venetian blinds employing reflecting and diffusing surfaces are an effective means of controlling the distribution of natural illumination as well as the glare from windows. Any devices for adjustment of natural lighting should be controlled by some specified individual.

Rapid changes in illumination levels result in a temporary inability to see because of the time required for adaptation of the eyes. An example of this occurs when one steps from bright sunlight into a dimly lighted interior. A passageway adjacent to a highly illuminated area, therefore, needs relatively high and graduated illumination. Again, where the eye has been afforded the advantages of a high illumination throughout the day, and artificial light is turned on to reinforce the failing natural light, a higher total illumination is ordinarily needed than at night under artificial lighting alone.

Natural light is subject to variation throughout the day and no individual can be relied upon in practice to determine by visual observation when more light should be added in the room or when artificial lighting can be spared. Practical equipment utilizing photoelectric tubes or light-sensitive cells has been developed for controlling the lighting automatically, although it is not applicable to all installations. These photoelectric relays can be relied upon to follow the changes of daylight and make corrections when needed even though the variation is too gradual to attract attention. They will turn on the artificial lighting when the natural illumination at a given point in the room falls below a predetermined value. If the daylight illumination then increases sufficiently, they will turn off the light. The photoelectric relay does not lag behind or make mistakes. It assures good seeing conditions at all times with a minimum expenditure of electricity for lighting consistent with this result.

Automatic control is recommended particularly for locations where critical seeing is done with daylight illumination. Frequently a man engrossed in his work will not notice the gradual diminution of daylight until he realizes he has a headache or reaches the point where he simply cannot see. When this happens to an entire department, the loss in employee efficiency is serious. The photoelectric relay stands guard over such eventualities. It is an inexpensive means of avoiding the penalties of insufficient illumination when reliance is placed on daylight as the principal source of light.[195]

ARTIFICIAL LIGHTING

To maintain good seeing conditions, artificial lighting must be supplied when daylight fails, as on dark and cloudy days or for the areas where an insufficient quantity of daylight penetrates. In some localities, deficient daylight conditions prevail during about two-thirds of the working hours. Even in comparatively sunny territories, measurements show that desirable daylight conditions are lacking for a surprisingly large percentage of the time. For this reason, artificial lighting is essential to good plant operation.

With natural lighting, the space along the windows is, in most plants, the best-lighted area, while with artificial lighting this space is too often the most poorly lighted. It is essential that the artificial lighting be so designed as to continue the general level of illumination close up to the windows and walls, thus insuring good lighting over the entire working area of the room, and to light the area adequately for night work.

General Lighting. Modern industrial lighting practice requires the establishment of a base or minimum quantity of light throughout the room, termed general lighting. This may vary depending upon the purpose for which the space is to be used. If the visual tasks are particularly severe, much higher illumination over restricted areas can be added upon this base. This additional light,[196] known as supplementary lighting, is usually provided by luminaires placed relatively close to the areas being illuminated. The general lighting system, in contrast, usually consists of luminaires placed 10 ft or more above the floor. The purpose of the general lighting system where there is also supplementary lighting is to keep the brightness contrast between the well-lighted immediate work area and the surroundings within a range which is comfortable to the eyes, to provide sufficient light for safety and protection, and to illuminate ordinary seeing tasks.

The general lighting, or the base quantity of light, should be quite uniform so that light will be available when needed at any point in the room. This is particularly desirable for interiors where the machine layout may be changed. If the general lighting has been designed for uniform illumination, machines may be moved without necessitating an expensive change in the overhead lighting system.

The manner in which the light from the lamp is controlled by the lighting equipment governs to a large extent the important effects of

glare, shadows, distribution, and diffusion. Luminaires are classified in accordance with the way in which they control the light, as shown in table 51.

TABLE 51

DISTRIBUTION OF ILLUMINATION BY DIFFERENT LUMINAIRES

Classification of Luminaire	*Approximate Distribution of Light* Upward	Downward
Direct	0– 10%	90–100%
Semidirect	10– 40%	60– 90%
General diffuse	40– 60%	40– 60%
Semi-indirect	60– 90%	10– 40%
Indirect	90–100%	0– 10%

Industrial lighting is usually of the *direct* type. This can be defined as a lighting system in which practically all (90 to 100%) of the light of the luminaires is directed downward, i.e., directly toward the usual working areas. While in general such systems provide illumination on the working surfaces most efficiently, this may be at the expense of other factors. For example, disturbing shadows may result unless the area of the lighting units is relatively large or they are placed relatively close together. With incandescent lamp units, shadows are at a minimum when the area of the luminaires is largest, as with the so-called skylight or light-hood types. The relatively large size of the fluorescent lamp tends to minimize shadows, and this is especially true when they are installed in continuous rows.

Direct and reflected glare may be distressing. Care should be taken to install the equipment to avoid exposing the workers' eyes to the glare from brilliant sources or excessive contrasts between the light source and its background.

There are two different types of equipment usually classified under this heading—distributing types and concentrating types. The distributing types comprise porcelain-enameled reflectors and diffusers and units with the various white baked-enamel and synthetic finishes. The widespread distribution of light can also be obtained with proper finish, contour, and configuration with aluminum, mirrored glass, prismatic glass, and similar finishes. This type of light distribution is advantageous in many industrial applications because a large proportion of the seeing tasks in industry involves the viewing of surfaces that are vertical or nearly so.

In general, distributing units provide adequately uniform illumination when they are spaced a distance approximately equal to the mounting height above the floor, exceptions being structures of high ceilings or high bays. The shielding angle (a term used for fluorescent equipment) of the entire light source should not be less than 13° below the horizontal, and a somewhat greater amount of shielding is desirable for filament lamp equipment. The term angle of cutoff is used for filament lamp equipment, and the angle is measured from the vertical.

Among the concentrating direct lighting units are the prismatic, mirrored-glass, and aluminum reflectors. These are most effectively used in narrow high bays and craneways where it is necessary to mount the reflector at a height as great or greater than the width of the area to be illuminated. In this case, a concentrated beam is necessary in order to get the light to the working area without excessive loss on the walls and windows. Spacing should be such as to provide uniform illumination over the working area. Such units are also frequently used in smaller sizes, some equipped with louvers for the supplementary lighting of specific work areas.

In *semidirect* lighting, 60 to 90% of the output of the luminaire is directed downward to the working surface. There is then some contribution to the illumination at the working plane from light which is directed upward and reflected downward by the ceiling and upper wall areas. For the most part, luminaires in this class are of the open-bottom type, though some have closed bottoms of glass or plastic material. They are quite suitable for such areas as corridors, stairways, washrooms, and locker rooms.

General diffuse lighting refers to systems where the predominant illumination on horizontal working surfaces comes directly from the lighting units but where there is also a considerable contribution from upward light reflected back from ceiling and upper wall areas. Luminaires of this type are frequently found in factory offices.

One type of unit of this classification is the glass, diffusing, enclosing globe. Diffusing globes should be of sufficient density to conceal completely the lamp within. If diffusing globes are used to provide the higher illuminations of table 50, they are likely to become too bright from the standpoint of both direct and reflected glare unless a very considerable area of surface is provided.

Another general type of unit in this classification is represented by the so-called louvered units, sometimes termed "direct indirect"

by which from 40 to 60% of the light emitted is directed upward and the remainder downward but with little or no light directed toward the sides.

While general diffuse lighting systems give more illumination for a specified wattage than do indirect or semi-indirect systems, shadows are more noticeable, and some difficulty may be experienced with both direct and reflected glare.

Semi-indirect lighting is defined as any system in which 60 to 90% of the luminaire output is emitted upward toward the ceiling and upper side walls, while the rest is directed downward. Because the ceiling constitutes an important part of such a lighting system, careful attention must be paid to having it as light in color as possible and to maintaining it in a good condition. In general, semi-indirect units give a little more light for the same wattage than do indirect units, but more attention must be given to the factors of direct and reflected glare. Luminaires of this classification are available in completely enclosed types which resist the collection of dust and dirt and are easily cleaned. There are also styles that are open both top and bottom so that there remains only the upper surface of the lamps to collect dust and dirt.

In *indirect* lighting, 90 to 100% of the light from the luminaires is first directed to the ceiling and upper walls from which it is reflected diffusely to all parts of the room. In effect, the entire ceiling and high walls become a light source. With such a large area serving as a source of light, little direct glare is experienced. Shadows are practically eliminated, and reflected glare is reduced. With many polished metal pieces, a maximum visibility is obtained of such things as ruled lines, figures, mars, or blemishes which are seen against the polished background. However, because the ceiling constitutes an important part of such a lighting system, careful attention must be paid to having it as light in color as possible and maintaining it in good condition. It should be given a flat white finish having a high reflection-factor. Recently there have been developed specially-configurated ceilings with semimatte finish that are designed to present reduced brightness at the angles at which they are normally seen.

The lighting units, which may have either opaque or luminous bottoms, should be such that they can be easily cleaned because a layer of dust and dirt absorbs a large amount of light.

This quality of lighting is highly desirable for such visual tasks as are found in drafting rooms and general and private offices.

Large-area sources of low uniform brightness approximate indirect lighting in effect. One measure of the quality of lighting which a given source will produce is the angle subtended by the source at the point of work. With three-dimensional work tasks, particularly of a specular or semispecular nature, this factor is of much importance. The most common large-area source is an indirect lighting system. However, there are many locations in industry where indirect lighting is impractical; for such cases, types of units which produce somewhat the same lighting effect are available. They consist of large luminous areas placed relatively close to the point of work. In this way, the subtended angle is of the same order of magnitude as a ceiling lighted with indirect units. For many locations throughout the actual working areas, such large-area sources are recommended. They are also effective for some office applications.

Supplementary Lighting. Supplementary lighting is necessary where the seeing task requires more light than is provided by the general illumination or where directional light is indicated.

Supplementary lighting should be specifically designed for the particular visual task. A number of specially designed luminaires are available which supplement the general lighting over a limited area. In this way, the light is confined to the immediate work area and does not become a source of glare to anyone in the room. Where a diffusing source of low brightness is needed, a large-area, low-brightness unit can be placed directly over the work zone.

It is often preferable for concentrating supplementary lighting units to be mounted at some distance from the point of work. Thus they cannot easily get out of adjustment and are not in the way of the workmen. This also eliminates the heat problem when filament lamps are used. Where a certain degree of adjustment is desirable, units can be mounted on flexible arms for manipulation by the workman to obtain the maximum advantage.

Suppementary lighting, however, should be specifically designed for the particular visual task. High illumination is usually provided with supplementary lighting, and care should be taken that the contrast between the bright work and darker surroundings is not too great. Sometimes the reverse must be guarded against; that is, having high brightnesses elsewhere in the field of vision. Though no two sets of conditions are exactly alike, in general, the brightness ratio from maximum to minimum should not exceed 10 to 1; a ratio of 5 to 1 is preferable. While the measurement of footcandles is not an accurate determination of brightnesses, it suffices

in most cases for this matter of satisfactory contrast; hence the common statement that with supplementary lighting the ratio of maximum to minimum foot-candles should not exceed 10 to 1.

Windowless Buildings. As natural light cannot be relied upon, this new type of industrial plant should be provided with general illumination sufficient in intensity for the most critical seeing task. Each employee is now accustomed to taking his unusually fine work to a window. This procedure will be impossible in windowless buildings. Therefore, a high level of good illumination must be installed for all regular operations, with supplementary lighting only where it is necessary to illuminate machines of an unusual shape.

An emergency lighting system is of particular importance in a windowless building.

CHAPTER XVI

INDUSTRIAL NOISE AND ITS CONTROL

Possibly the simplest definition of noise is that it is objectionable sound. It may be objectionable because of its absolute intensity or loudness, such as the roar of a nearby airplane motor or a riveter, or because of its relative loudness, such as conversation in a library reading room or a carpenter making repairs in an office room.

TABLE 52

RELATION OF NOISE LEVEL IN DECIBELS TO THE ACTUAL PHYSICAL INTENSITY OF THE SOUND

Noise Level (decibels)	*Physical Intensity*	*Examples*
0	1	Threshold of hearing
10	10	Whisper at five feet
20	10^2	Very quiet room
30	10^3	Quiet private office
40	10^4	Subdued conversation
50	10^5	Business office
60	10^6	Ordinary conversation
70	10^7	Busy city traffic
80	10^8	Chicago elevated at street level
90	10^9	Pneumatic drill at 10 ft
100	10^{10}	Subway express passing local station
110	10^{11}	Airplane propeller noise
120	10^{12}	Same at 10 ft
130	10^{13}	Threshold of painful sound

The common unit of noise measurement is the decibel. It is not a measure of the physical intensity of sound but is an index of its relative loudness to the human ear. The relationship between noise level in decibels and its physical intensity is given in table 52. Everyday examples of sounds having the various noise levels are shown also to give the reader a mental picture of what the different loudness levels constitute. Examples of noise level ranges actually measured at a distance of 3 ft from some common industrial machines or operations are given in table 53. It will be noted that

most of these values are above 90 decibels, which is considered an objectionable and harmful level as will be indicated later. The intensity of sound produced by normal conversation lies in the range of about 40 to 70 decibels.

Noise is measured by a sound-level meter, frequently called a decibel meter. It consists essentially of a microphone, a high-gain audioamplifier, and a rectifying milliammeter which reads directly in decibels. Since such meters were designed to measure the rela-

TABLE 53

NOISE LEVELS PRODUCED BY DIFFERENT MACHINES AT A DISTANCE OF 3 FT

Machine or Operation	*Noise Level (decibels)*
Punch presses	96–103
Drop hammers	99–101
Bumping hammer	100
Hydraulic press	130
Automatic riveters	95– 99
Lathes (average)	80
Automatic screw machines	93–100
Airplane riveting guns	94–105
Airplane propeller grinding	100–105
Looms	94–101
Wood planers	98–110
Wood saw	100

tive loudness as registered by the human ear, they have been made to read in decibels rather than in a unit representing the physical intensity. As is evident from table 52, there is a relationship between decibels and the physical intensity; the noise level in decibels is 10 times the logarithm of the physical intensity.

The machine age, mechanization, and speeded-up production have brought with them increased industrial noise and the problems created thereby. There seems to be abundant proof both practical and experimental that noise produces deafness or impaired hearing and neuroses.[197] Noise levels of 120 decibels are painful, 90 decibels and above have been shown to be harmful to the human ear,[198] and prolonged exposure to even lower levels has been reported to cause deafness.[199] Of 1040 workers in noisy industries examined for deafness the highest percentage of hearing impairment for any age group was from the noisiest industries. Deafness from noise develops gradually and often unnoticed. There are six factors which influence the degree of hearing loss caused by exposure.[200] These are

(1) intensity of noise, (2) length of exposure per period, (3) total exposure time, (4) character of the sound, whether continuous or interrupted; (5) surroundings, whether in enclosed or open spaces, and (6) previous aural disease.

In addition to permanent hearing impairment, temporary deafness is caused by relatively short exposure to high noise intensity. According to one report, a 10-hour exposure to the noise level in a two-engine bomber (115 decibels) produced a measured loss of hearing as great as 30 decibels in some cases, and complete recovery of normal hearing ability required 36 hours.[201] The potential safety hazard created by such conditions is readily apparent.

Other authors [202, 203] show rather conclusively that the nervous tension increases as noise increases and suggest that nervous fatigue is caused by continued exposure to high noise levels.

The influence of noise on efficiency and accuracy appears to be open to question at present. There are several cases on record in which rather large increases in efficiency and decreases in spoilage with reduced noise have been reported.[201] For example (1) a noise reduction of 8 decibels in a large office building is reported to have resulted in an 8.8% increase in efficiency and a 25% decrease in errors, and (2) moving a temperature regulator assembly department away from a very noisy operation produced a 37% increase in output and a 68% decrease in rejections.

Contrary to these reports is that of a laboratory study on six subjects in which it was found that [204]

1. Output for 4 out of 7 tasks was higher at 90 decibels than at 72 decibels.
2. Accuracy did not appear to be affected significantly by noise.
3. Variability of performance was not affected markedly by noise changes.
4. Pulse rate and oral temperature were not affected markedly by changes in noise levels from 72 to 90 decibels.

On the basis of these contradictory reports it is difficult to say at present whether noise in the order of 90 decibels does or does not affect adversely the accuracy and efficiency of workers.

There seems to be little doubt that abrupt changes in noise levels are safety hazards even though it is difficult to evaluate their significance quantitatively. Whether noise plays the important part claimed for it as an indirect cause of accidents through fatigue is open to question.[205] However, noise as it interferes with hearing

shouted or sounded warnings of impending danger is a valid and important indirect cause of accidents. There can be little doubt also that noise is a nuisance not only as regards its intensity in decibels but as regards its comparative loudness. As indicated previously the noise of carpenters is not objectionable to themselves when sawing and hammering, but it would certainly interfere with the normal operations in an office building.

Since noise has been shown to produce hearing defects and nervous tension and to be a nuisance in many instances, it is desirable and sometimes necessary to control it or to reduce its intensity in the worker's ears sufficiently to render it harmless or to eliminate it as a nuisance. This may be accomplished by one or more of the following methods:

1. Elimination at the source.
2. Isolation of the noisy operations.
3. Reduction of noise by sound insulation.
4. Personal protective devices.

Elimination of noise at its source, as with any other industrial hazard, is fundamental. Architects and engineers can no longer consider a building layout or a piece of equipment as an entity, it must be considered with the operator or human factor in mind. It is much easier to prevent a noise hazard in the original design or layout than to correct it later.

The causes of much unnecessary noise in industry are faulty design of equipment, worn machine parts, improper mounting of equipment, improper location of machines, use of wrong type of material, and carelessness in operation of equipment. Suggested corrective measures are (1) replace worn parts early, (2) maintain all operating equipment in a first-rate condition, (3) use well-balanced parts, (4) keep moving parts well oiled, (5) substitute noiseless operations or machines for noisy ones, (6) mount machinery on sound-proof bases, (7) use proper materials, (8) install equipment and guards so that they will not vibrate, and (9) replace noisy gears with direct drive, belt drive, or nonmetallic gears, or house them in an oil bath. A good example of noise reduction by substitution of a different operation is that of pressure riveting or welding for pneumatic riveting. Similarly a very noisy condition was corrected by covering inspection tables in a small-parts assembly line with a wood-like material to prevent the clatter of metal on metal as the parts were conveyed along the line.

Not all industrial noise can be eliminated at its source. However, the number of people affected by noisy operations may be reduced to a minimum by *isolating* such operations. Noise-producing machines or equipment frequently require only a relatively few attendants. Yet many workers may be exposed to the noise created by them by virtue of the fact that they are located nearby or in the same room. In planning new factories or plants the noisy machines should be bunched as much as flow of material will permit and should be housed in well-insulated enclosures so that only the immediate attendants are exposed to the din created by them. The exposed workers may then be protected by means of ear defenders. In existing factories and industries, noisy machines should be enclosed separately in sound-absorbing booths or rooms. Sometimes it is possible to house only the noise-producing part of the machine or equipment in a sound-absorbing enclosure, in other instances the entire machine and the attendant must be enclosed. A good example of noise prevention by this method is that of testing airplane motors in which the motor test rooms are so well insulated that little noise escapes from them.

A common method of controlling noise is that of *sound insulation.* This method is particularly adapted to conditions where much of the noise results from reflection back and forth between the walls, floors, ceilings, or other large surfaces. It is particularly successful for office buildings and is being used on an ever-increasing scale for this purpose.

The use of sound absorbing material is, however, not limited to offices, even though its application to noisy operations in industry is not as common. As indicated previously, sound-absorbing enclosures for noisy machines or parts thereof afford an effective method of reducing the noise level to an unobjectionable value. Sound-insulating material may also be used in reverse in which the worker or workers requiring relative quiet may be isolated in sound-proof enclosures. The effectiveness of such procedure is demonstrated very well by insulated or sound-absorbent telephone booths in subway stations.

Information on the mechanics of using sound-absorbing materials is given in reference 206.

If it is not feasible to reduce the worker's exposure to noise by one of the foregoing methods, he may and should be protected by means of a suitable *ear-protection device.* Much work has been done in developing more comfortable and more effective devices of this kind

in recent years, and today there are available commercially several satisfactory devices.[207, 208, 209]

The primary objective in designing an ear protector is to obtain selective elimination so that the higher intensity noises are reduced proportionately more than the lower intensity ones. This is, of course, not accomplished with the common wad of cotton but has been achieved with some of the commercial protectors. According to one report,[208] the wearer of a particular type of protector can hear announcements over a public address system better than one without such devices if the surrounding noise is 75 decibels or higher. Selective reduction is extremely important in the very noisy industries, particularly if they involve considerable danger from moving objects. It is essential in such cases that the wearer be able to hear the warning call or gong in case of danger.

All employees in noisy areas or at noisy operations should have their hearing tested periodically, preferably as part of their routine periodic physical examination. Those found to have any evidence of hearing impairment should be required to wear appropriate ear protectors.

CHAPTER XVII

PLANT SANITATION AND HYGIENE

The subject matter of this chapter is a complete study within itself. It lies to a large extent outside the scope of industrial health engineering except insofar as plant sanitation and atmospheric sanitation are interrelated. Good plant sanitation is essential to good atmospheric sanitation, and vice versa. The goal of atmospheric sanitation is largely occupational-disease prevention; that of plant sanitation is communicable-disease prevention. Occupational-disease prevention deals largely with nonliving matter, communicable-disease prevention with living organisms. The objectives in both pursuits are the same—to reduce illness and lost time.

Since plant sanitation is seldom a major responsibility of the industrial hygiene engineer, the subject will not be dealt with in detail. By the same token, however, he must have some knowledge of the principles and requirements of good plant sanitation since they are so closely allied with those of atmospheric sanitation.

Plant sanitation has to do essentially with (1) housekeeping, (2) water supply and drinking facilities, (3) eating facilities, (4) wash- and locker-room facilities, (5) rest rooms for women, (6) toilet facilities, and (7) waste collection and disposal. The recommended minimum requirements for each of these separate items to accomplish satisfactory plant sanitation are summarized in convenient form in the following sections.

Housekeeping. 1. All places of employment, passageways, storerooms, and service rooms should be kept in a sanitary condition, and the premises including the yards, courts, passages, areas, and alleys connected with the place of employment should be kept free from any accumulation of dirt, filth, rubbish, or garbage.

2. All products, supplies and materials, and parts and equipment should be stored in shelves, bins, lockers, or other appropriate places provided for them, consistent with efficient operation. They should be piled or stored in such manner as not to cause an accident to any employee.

3. The floors of all buildings in which employees work should be maintained in a clean condition and insofar as possible in a dry condition, consistent with the type of operations carried on. Where wet processes are in operation regularly causing wet floor conditions, the floors should be drained as well as practicable, and/or false floors, platforms, mats, duckboards, or other dry standing places should be provided.

4. Floor and other walkway surfaces should be kept in good repair and free from oil, water, protruding nails, splinters, holes, and loose boards.

5. So far as is practicable, sweeping and cleaning should be done outside of working hours and in such manner as to avoid the dissemination of dust. All sweepings, waste, refuse, and garbage should be removed as often as necessary to maintain the place of employment in a sanitary condition.

6. Expectorating upon the walls, floors, stairs, or equipment should be prohibited. Where cuspidors are needed, they should be of the paper disposable type or should be cleaned daily.

7. Wherever mechanical or chemical equipment is used to maintain sanitation, periodic inspection is required to assure the efficiency of such equipment, and a record should be kept of the results of each inspection.

Water Supply and Drinking Facilities. 1. There should be provided in all places of employment, and readily accessible to the employees, a supply of clean, cool, wholesome, and safe drinking water approved by the local authorities having jurisdiction.[210, 211] A supply of similar drinking water should also be provided in all rooms assigned for eating purposes. Drinking-water facilities should not be provided in toilet rooms or privies. When safe water is not available, the state authorities should furnish directions for rendering it safe for human consumption.

2. The temperature of the water supplied for drinking purposes should not be lower than 40° F nor higher than 80° F (preferably between 45° and 50° F), and, if cooled by ice, the ice should not come in direct contact with the water.

3. Where drinking fountains are provided, at least one sanitary fountain of an approved type and construction should be provided for each 50 employees. Approved sanitary drinking fountains shall meet the following requirements: [212, 213]

a. The fountain should be constructed of impervious material, such as vitreous china, porcelain, enameled cast iron, other metals, or stoneware.

b. The jet of the fountain should issue from a nozzle of nonoxidizing, impervious material set at an angle from the vertical such as to prevent the return of water in the jet to the orifice or orifices from which the jet issues. The nozzle and every other opening in the water pipe or conductor leading to the nozzle should be above the edge of the bowl so that such nozzle or opening will not be flooded if a drain from the bowl of the fountain becomes clogged.

c. The end of the nozzle should be protected by nonoxidizing guards to prevent the mouth and nose of persons using the fountain from coming into contact with the nozzle. Guards should be so designed that the possibility of transmission of infection by touching the guards is reduced to a minimum.

d. The inclined jet of water issuing from the nozzle should not touch the guard and thereby cause splattering.

e. The bowl of the fountain should be so designed and proportioned as to be free from corners which would be difficult to clean or which would collect dirt.

f. The bowl should be so proportioned as to prevent unnecessary splashing at a point where the jet falls into the bowl.

g. The drain from the fountain should not have a direct physical connection with a waste pipe, unless the drain is trapped.

h. The water supply should be equipped with an adjustable valve fitted with a loose key or an automatic valve permitting the regulation of the rate of flow of water to the fountain so that the valve manipulated by the users of the fountain will merely turn the water on and off.

i. The height of the fountain at the drinking level should be such as to be most convenient to persons using it.

j. The waste opening and pipe should be of sufficient size to carry the water away promptly, and should be provided with a strainer.

4. The common drinking cup should be prohibited. When individual drinking cups (to be used only once) are supplied, a suitable dispenser should be provided for the unused cups and a receptacle for the disposal of the used cups.

5. Open containers, whether fitted with a cover or not, such as barrels, pails, or tanks from which water must be dipped or poured, should not be used for drinking-water purposes, except that drinking water for mobile labor crews, such as construction gangs, may be supplied with portable pressure drinking devices having an approved sanitary fountain, and thermos bottles may be used for drinking water for individual use by employees in remote or hard-to-get-to places such as crane cabs.

6. Where water from an unapproved source is used for industrial processes or fire protection, notices should be posted stating clearly that such water is unsafe for drinking, and every reasonable effort should be made to prevent its being so used.

Eating Facilities. 1. In all places of employment where employees are permitted to lunch on the premises, adequate space suitable for

that purpose should be provided for the maximum number of persons who may use such space at one time.

2. A covered receptacle should be provided for disposing of all waste food, and employees should use it for that purpose.

3. No employee should be permitted to partake of any part of his lunch or eat other food at any time, where any industrial poison or other substance that may be injurious to his health is present.

4. In every establishment where there is exposure to injurious dusts or other toxic materials, a separate lunchroom should be maintained

TABLE 54

LUNCHROOM AREAS RECOMMENDED

Maximum Number of Persons Using Lunchroom at One Time	*Square Feet per Person*
Less than 25	8
25 to 74	7
75 to 149	6
150 to 500	5
More than 500	4

unless it is convenient for the employees to lunch away from the premises. Suitable and accessible locker rooms may be used for eating lunches if special lunch rooms or canteens are not available. All employees working in contaminated or "toxic" areas should be required to wash before eating, and suitable facilities for this purpose should be provided. The size of the lunchroom should be based on the data given in table 54. At least one-half hour should be allowed each employee for lunch.

5. Wherever a café or cafeteria is provided within the plant it should be constructed, maintained, and operated in conformance with U. S. Public Health Service[214, 215] or local health regulations pertaining to public eating and drinking establishments, whichever is the more rigid.

Wash- and Locker-Room Facilities. 1. Adequate facilities for maintaining personal cleanliness should be provided in every place of employment and should be maintained in a sanitary condition throughout. Wash- and locker-room facilities should be provided for each sex when the number of either sex exceeds 10 regular employees on any single work shift. Locker-room floor space should be at least 4.5 sq ft per facility.

2. Clothes racks, lockers, locker baskets, or suspended devices should be provided for every employee regardless of whether a wash and locker room is required.

3. Lavatory and/or shower-bath facilities should be provided on the basis of the data contained in table 55. Lavatories may consist of individual units, wash sinks, or circular fountains. Where wash sinks or circular fountains are used, 24 in. of outside rim of a wash sink and 17 in. of outside rim of a circular fountain will constitute the equivalent of one lavatory.

TABLE 55

Number of Washing Facilities Recommended

Maximum Number of Persons Using Washing Facilities at One Time	*Number of Washing Facilities*
15	1
30	2
50	3
For each additional 25 persons	1 additional

4. If workers are exposed to skin contamination with poisonous, infectious, or irritating materials, particularly those which may cause poisoning by absorption through the skin, shower facilities numbering at least twice as many as given in table 55 should be provided for such employees, and each employee should be required to take a supervised bath at the end of the shift and should change clothes completely before and after work. Two lockers, one for street and one for work clothes, are recommended. The lockers should be located at different ends of the locker and wash room as regards movement through it when the workers go to or from the place of work.

5. Every new wash basin installed should be made of vitreous, glazed, or enameled ware or similar material. Galvanized cast iron may be permitted for sinks.

6. The walls and floor of the wash and locker room should be constructed of materials and in a manner obviously suited for the purpose.

7. The common towel is prohibited. Individual towels of cloth or paper and proper receptacles for disposing of used towels should be provided.

8. Soap in a suitable dispenser should be provided at each wash place. No strong alkali or harsh soaps should be permitted.

9. Oils or solvents used for removing contaminants from skin should be used sparingly.

10. Water from any source not approved by the state or local authorities should not be used for washing.

Rest Rooms for Women. 1. Every establishment employing more than 5 women should provide a rest room for them located adjacent to the women's toilet room and connecting by means of a door, except that if the establishment has a hospital or medical dispensary on the premises equipped with cots or beds, a rest room will not be required where the total number of regular female employees per shift does not exceed 100.

TABLE 56

NUMBER OF TOILET FACILITIES RECOMMENDED [216]

Maximum Number of Regular Employees per Single Shift		*Number of Toilet Facilities*
Male	Female	
1 to 9	1 to 8	1
10 to 24	9 to 20	2
25 to 49	21 to 40	3
50 to 74	41 to 60	4
75 to 99	61 to 80	5
Over 99	—	1 per additional 30
	Over 80	1 per additional 26

2. No rest room should contain less than 60 sq ft of gross floor area, and an additional 2 sq ft should be provided for each female employee over 10 and up to 100. If over 100 females are regularly employed on any single shift, the rest-room floor area should be 240 sq ft plus 1½ sq ft for each female employee in excess of 100.

3. One cot, couch, or bed should be provided when 100 females or less are regularly employed per shift. When more than 100 are regularly employed per shift, cots, couches, or beds should be provided on the basis of one for each additional 250 females, or fraction thereof. Chairs or benches should also be provided.

Toilet Facilities. 1. Every place of employment should be provided with adequate water closets, chemical closets, or privies separate for each sex in accordance with the minimum requirements given in table 56.[216]

2. Chemical closets and privies should not be permitted except where no sewer is accessible and only when they can be kept under careful supervision.

3. All chemical closets should be of a type approved by the health authorities having jurisdiction and should be maintained in a sanitary condition. The containers should not be allowed to become more than two-thirds full and contents should be disposed of in an approved manner.

4. Privies should not be permitted in establishments employing more than 25 persons. All privies should be constructed and maintained as given in reference 217. No privy should be permitted within 100 ft of any room where foodstuffs are stored or handled nor should it be constructed at any place where it can contaminate any source of drinking water.

5. Covered receptacles should be kept in all toilet rooms used by females.

6. An adequate supply of toilet paper in proper holders should be provided in each toilet room.

7. Adequate washing facilities should be provided in every toilet room or any room adjacent thereto unless the general washing facilities are on the same floor and in close proximity to the toilet rooms.

8. Toilet rooms should be not more than one floor above or below the regular place of work of the persons using them unless passenger elevators are available for the employees' use in going to and from toilet rooms.

9. Whenever urinals are provided, one closet less than the number specified in table 56 may be provided for males for each urinal, except that the number of closets in such cases may not be reduced to less than two-thirds the number specified in the table. Urinals should be made of materials impervious and resistant to moisture. The floor to a distance of not less than 24 in. in front of all urinals should be constructed of waterproof materials and should slope toward the urinal trough for all "floor-level" urinals. Every urinal should have an individual flush system using not less than 1 gal of water per discharge. Water may be allowed to run continuously over slab urinals in place of a flush system.

10. The walls of compartments or partitions between fixtures may be less than the height of room walls, but the top should be not less than 5 ft from the floor and the bottom not more than 1 ft from the floor. Compartment doors should be supplied with latches.

11. Toilet rooms should be fitted with self-closing doors which should be screened from workrooms. Toilet-room floors and walls to a height of 6 in. should be constructed of material impervious and resistant to moisture. Floors, walls, and ceilings should be of ma-

terial easy to clean. All toilet rooms having windows should be equipped with screens. The windows should be translucent but not transparent.

12. In new installations the minimum floor space allotted for toilet facilities (closets), lavatories (wash basins), and urinals should be as given in table 57.[218, 219]

13. The construction and maintenance of toilet fixtures should comply with the state or local building and plumbing codes, where such codes exist. Otherwise the instructions in reference 220 can be followed. The water-closet bowl should be set free and open from

TABLE 57

SPACE ALLOTMENT FOR TOILET FACILITIES

Facility	*Minimum Width (inches)*	*Minimum Depth (inches)*	*Minimum Floor Space (square feet)*
Closets	32	44	16
Lavatories	24	44	12
Urinals	24	44	12

all enclosing walls so that space around the fixture may be cleaned easily. If the water-closet seat is of absorbent material it should be finished with light-colored varnish or another substance impervious to moisture.

Waste Collection and Disposal. 1. Waste receptacles of a type which can be kept clean and sanitary should be provided in all places of employment; they should be located at places convenient to as many workers as possible.

2. An adequate number of waste receptacles of a type suitable for the purpose should be provided in and near all eating places, including lunchrooms and canteens.

3. Waste receptacles should be covered unless they contain nothing which will attract flies.

4. All waste receptacles should be emptied and cleaned as often as is necessary to maintain them in a sanitary condition.

5. All waste should be collected routinely and disposed of in a manner approved by the state health department.

6. Sewage likewise should be disposed of in a manner approved by the local health authority having jurisdiction or by the U. S. Public Health Service.[221]

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TABLE A

Conversion Values for Gases and Vapors—Parts per Million by Volume versus Milligrams per Liter

(77° F and 760 mm Hg)

Molecular Weight	1 Mg/L-ppm	1 ppm-Mg/L	Molecular Weight	1 Mg/L-ppm	1 ppm-Mg/L	Molecular Weight	1 Mg/L-ppm	1 ppm-Mg/L
1	24,450	0.0000409	51	479	0.002086	101	242.1	0.00413
2	12,230	0.0000818	52	470	0.002127	102	239.7	0.00417
3	8,150	0.0001227	53	461	0.002168	103	237.4	0.00421
4	6,113	0.0001636	54	453	0.002209	104	235.1	0.00425
5	4,890	0.0002045	55	445	0.002250	105	232.9	0.00429
6	4,075	0.0002454	56	437	0.002290	106	230.7	0.00434
7	3,493	0.0002863	57	429	0.002331	107	228.5	0.00438
8	3,056	0.000327	58	422	0.002372	108	226.4	0.00442
9	2,717	0.000368	59	414	0.002413	109	224.3	0.00446
10	2,445	0.000409	60	408	0.002454	110	222.3	0.00450
11	2,223	0.000450	61	401	0.002495	111	220.3	0.00454
12	2,038	0.000491	62	394	0.00254	112	218.3	0.00458
13	1,881	0.000532	63	388	0.00258	113	216.4	0.00462
14	1,746	0.000573	64	382	0.00262	114	214.5	0.00466
15	1,630	0.000614	65	376	0.00266	115	212.6	0.00470
16	1,528	0.000654	66	370	0.00270	116	210.8	0.00474
17	1,438	0.000695	67	365	0.00274	117	209.0	0.00479
18	1,358	0.000736	68	360	0.00278	118	207.2	0.00483
19	1,287	0.000777	69	354	0.00282	119	205.5	0.00487
20	1,223	0.000818	70	349	0.00286	120	203.8	0.00491
21	1,164	0.000859	71	344	0.00290	121	202.1	0.00495
22	1,111	0.000900	72	340	0.00294	122	200.4	0.00499
23	1,063	0.000941	73	335	0.00299	123	198.8	0.00503
24	1,019	0.000982	74	330	0.00303	124	197.2	0.00507
25	978	0.001022	75	326	0.00307	125	195.6	0.00511
26	940	0.001063	76	322	0.00311	126	194.0	0.00515
27	906	0.001104	77	318	0.00315	127	192.5	0.00519
28	873	0.001145	78	313	0.00319	128	191.0	0.00524
29	843	0.001186	79	309	0.00323	129	189.5	0.00528
30	815	0.001227	80	306	0.00327	130	188.1	0.00532
31	789	0.001268	81	302	0.00331	131	186.6	0.00536
32	764	0.001309	82	298	0.00335	132	185.2	0.00540
33	741	0.001350	83	295	0.00339	133	183.8	0.00544
34	719	0.001391	84	291	0.00344	134	182.5	0.00548
35	699	0.001432	85	288	0.00348	135	181.1	0.00552
36	679	0.001472	86	284	0.00352	136	179.8	0.00556
37	661	0.001513	87	281	0.00356	137	178.5	0.00560
38	643	0.001554	88	278	0.00360	138	177.2	0.00564
39	627	0.001595	89	275	0.00364	139	175.9	0.00569
40	611	0.001636	90	272	0.00368	140	174.6	0.00573
41	596	0.001677	91	269	0.00372	141	173.4	0.00577
42	582	0.001718	92	266	0.00376	142	172.2	0.00581
43	569	0.001759	93	263	0.00380	143	171.0	0.00585
44	556	0.001800	94	260	0.00384	144	169.8	0.00589
45	543	0.001840	95	257	0.00389	145	168.6	0.00593
46	532	0.001881	96	255	0.00393	146	167.5	0.00597
47	520	0.001922	97	252	0.00397	147	166.3	0.00601
48	509	0.001963	98	249.5	0.00401	148	165.2	0.00605
49	499	0.002004	99	247.0	0.00405	149	164.1	0.00609
50	489	0.002045	100	244.5	0.00409	150	163.0	0.00613

TABLE A (*Continued*)

CONVERSION VALUES FOR GASES AND VAPORS—PARTS PER MILLION BY VOLUME VERSUS MILLIGRAMS PER LITER

(77° F and 760 mm Hg)

Molecular Weight	1 Mg/L-ppm	1 ppm-Mg/L	Molecular Weight	1 Mg/L-ppm	1 ppm-Mg/L	Molecular Weight	1 Mg/L-ppm	1 ppm-Mg/L
151	161.9	0.00618	201	121.6	0.00822	251	97.4	0.01027
152	160.9	0.00622	202	121.0	0.00826	252	97.0	0.01031
153	159.8	0.00626	203	120.4	0.00830	253	96.6	0.01035
154	158.8	0.00630	204	119.9	0.00834	254	96.3	0.01039
155	157.7	0.00634	205	119.3	0.00838	255	95.9	0.01043
156	156.7	0.00638	206	118.7	0.00843	256	95.5	0.01047
157	155.7	0.00642	207	118.1	0.00847	257	95.1	0.01051
158	154.7	0.00646	208	117.5	0.00851	258	94.8	0.01055
159	153.7	0.00650	209	117.0	0.00855	259	94.4	0.01059
160	152.8	0.00654	210	116.4	0.00859	260	94.0	0.01063
161	151.9	0.00658	211	115.9	0.00863	261	93.7	0.01067
162	150.9	0.00663	221	115.3	0.00867	262	93.3	0.01072
163	150.0	0.00667	213	114.8	0.00871	263	93.0	0.01076
164	149.1	0.00671	214	114.3	0.00875	264	92.6	0.01080
165	148.2	0.00675	215	113.7	0.00879	265	92.3	0.01084
166	147.3	0.00679	216	113.2	0.00883	266	91.9	0.01088
167	146.4	0.00683	217	112.7	0.00888	267	91.6	0.01092
168	145.5	0.00687	218	112.2	0.00892	268	91.2	0.01096
169	144.7	0.00691	219	111.6	0.00896	269	90.9	0.01100
170	143.8	0.00695	220	111.1	0.00900	270	90.6	0.01104
171	143.0	0.00699	221	110.6	0.00904	271	90.2	0.01108
172	142.2	0.00703	222	110.1	0.00908	272	89.9	0.01112
173	141.3	0.00708	223	109.6	0.00912	273	89.6	0.01117
174	140.5	0.00712	224	109.2	0.00916	274	89.2	0.01121
175	139.7	0.00716	225	108.7	0.00920	275	88.9	0.01125
176	138.9	0.00720	226	108.2	0.00924	276	88.6	0.01129
177	138.1	0.00724	227	107.7	0.00928	277	88.3	0.01133
178	137.4	0.00728	228	107.2	0.00933	278	87.9	0.01137
179	136.6	0.00732	229	106.8	0.00937	279	87.6	0.01141
180	135.8	0.00736	230	106.3	0.00941	280	87.3	0.01145
181	135.1	0.00740	231	105.8	0.00945	281	87.0	0.01149
182	134.3	0.00744	232	105.4	0.00949	282	86.7	0.01153
183	133.6	0.00748	233	104.9	0.00953	283	86.4	0.01157
184	132.9	0.00753	234	104.5	0.00957	284	86.1	0.01162
185	132.2	0.00757	235	104.0	0.00961	285	85.8	0.01166
186	131.5	0.00761	236	103.6	0.00965	286	85.5	0.01170
187	130.7	0.00765	237	103.2	0.00969	287	85.2	0.01174
188	130.1	0.00769	238	102.7	0.00973	288	84.9	0.01178
189	129.4	0.00773	239	102.3	0.00978	289	84.6	0.01182
190	128.7	0.00777	240	101.9	0.00982	290	84.3	0.01186
191	128.0	0.00781	241	101.5	0.00986	291	84.0	0.01190
192	127.3	0.00785	242	101.0	0.00990	292	83.7	0.01194
193	126.7	0.00789	243	100.6	0.00994	293	83.4	0.01198
194	126.0	0.00793	244	100.2	0.00998	294	83.2	0.01202
195	125.4	0.00798	245	99.8	0.01002	295	82.9	0.01207
196	124.7	0.00802	246	99.4	0.01006	296	82.6	0.01211
197	124.1	0.00806	247	99.0	0.01010	297	82.3	0.01215
198	123.5	0.00810	248	98.6	0.01014	298	82.0	0.01219
199	122.9	0.00814	249	98.2	0.01018	299	81.8	0.01223
200	122.3	0.00818	250	97.8	0.01022	300	81.5	0.01227

TABLE B

Conversion Factors

1 cubic meter equals 35.32 cubic feet
1 cubic foot equals 28.32 liters
1 cubic foot equals 7.48 gallons (U. S.)

1 meter equals 3.28 feet
1 meter equals 39.37 inches
1 inch equals 25.40 millimeters
1 inch equals 25,400 microns

1 kilogram equals 2.20 pounds
1 pound equals 453.6 grams
1 ounce equals 28.35 grams

1 cubic foot of water at 62° F weighs 62.32 pounds
1 gallon (U. S.) of water weighs 8.33 pounds
1 cubic foot of air at standard conditions weighs 0.075 pound

1 pound per square inch equals 2.30 feet of water
1 inch of mercury equals 13.57 inches of water
1 inch of mercury equals 0.49 pounds per square inch
1 atmosphere equals 14.70 pounds per square inch
1 atmosphere equals 29.92 inches of mercury

1 Btu equals 0.25 large calories
1 Btu equals the heat required to raise the temperature of 1 pound of water 1° F
1 Btu equals the heat required to raise the temperature of 55 cubic feet (approximately) of air 1° F

1 horsepower equals 550 foot-pounds per second
1 horsepower equals 0.75 kilowatt

Degrees F equal 1.8 times degrees C plus 32
π equals 3.1416
Circumference of a circle equals πd
Area of a circle equals $\pi d^2/4$
Surface area of a sphere equals πd^2
Volume of a sphere equals $\pi d^3/6$

TABLE C

APPROXIMATE COMPOSITION OF SOME ORGANIC SOLVENTS USED AS THINNERS

Name or Trade Name of Product	Composition (Per Cent)			Boiling Range (° C)
	Aromatics (mac 50–200 ppm) (1)	Alcohols, Esters, Ethers, and Ketones (mac 200–400 ppm) (2)	Paraffins and Naphthenes (mac 500–1000 ppm) (3)	
Acme Paint Thinner	25	60	15	70–125
AMI Thinner			100	100–250
ANA Thinner (enamel)		100		82–128
Apco Thinner	14		86	122–147
Bitumastic Thinner			100	151–191
Black Nitrocellulose Lacquer Enamel	10	50	40	70–140
Black Stencil Paint Thinner			100	158–195
Brit-Mark Stencil Ink Thinner		65	35	125–180
Butyl Cellosolve Thinner		100		171
Carbitol		100		198
Cellulose Nitrate Lacquer Thinner		60	40	70–125
Chocolate Brown Lacquer Thinner	5	50	45	65–120
Chromated Lacquer Thinner (Reducer 66)	100			
Duco 3614		60	40	37–147
Duco Thinner (K–1486)	29	42	29	64–142
du Pont 200 Paint Thinner	55		45	187–226
du Pont 3322 Lacquer Thinner	30	50	20	75–139
du Pont Lacquer Thinner 3673		45	55	85–180
du Pont "Red" Thinner 3450		70	30	60–120
du Pont Synthetic Reducer (T–8879)			100	80–125
du Pont Synthetic Reducer (T–8879)	25		75	136–204
du Pont Thinner Mix		50	50	
Enamel Thinner			100	90–120
Ethyl Cellulose Lacquer Thinner	15	50	35	78–143
Gensol		Turpentine		145–175

TABLE C (*Continued*)

APPROXIMATE COMPOSITION OF SOME ORGANIC SOLVENTS USED AS THINNERS

Name or Trade Name of Product	Composition (Per Cent)			Boiling Range (° C)
	Aromatics (mac 50–200 ppm) (1)	Alcohols, Esters, Ethers, and Ketones (mac 200–400 ppm) (2)	Paraffins and Naphthenes (mac 500–1000 ppm) (3)	
Glyptal Thinner	73		27	126–143
Hydro 1—Reducing—Specification 2	75		25	100–145
Hydro Flex 195 Paint Thinner	22		78	118–187
Ink Paste Thinner			100	165–201
Ink Reducer	1		99	153–205
Ink Thinner 77		100		77– 97
Insulating Varnish Thinner 5052	97		3	79–126
Japan Dryer			100	150–210
Lacquer Enamel Thinner	35	40	25	70–135
Lacquer Thinner	45	25	30	
Lacquer Thinner	20	50	30	
Lacquer Thinner	11	51	38	69–134
Lacquer Thinner	15	45	40	72–137
Lacquer Thinner 250–C–636	15	55	30	75–140
Lacquer Thinner 1055A	2	72	26	78–120
Lacquer Thinner 1173B	20	52	28	79–141
Lacquer Thinner (FL–19830)	15	60	25	80–139
Lacquer Thinner (FL–20300)	5	60	35	72–135
Lacquer Thinner (U. L. 10045)	15	60	25	70–140
Mineral Spirits			100	156–198
Naphtha	5		95	88–150
Naphtha	10		90	96–143
Nitrocellulose Lacquer Thinner	45	35	20	75–140
Nitrocellulose Nitrate Dope Thinner	30	55	15	75–140
N. R. C. Thinner	3	70	27	67–121
O'Brien Lacquer Thinner (L–165–3)	46	30	24	
Paint 29232A Thinner			100	98–136

TABLE C (*Continued*)

APPROXIMATE COMPOSITION OF SOME ORGANIC SOLVENTS USED AS THINNERS

Name or Trade Name of Product	Composition (Per Cent) Aromatics (mac 50–200 ppm) (1)	Alcohols, Esters, Ethers, and Ketones (mac 200–400 ppm) (2)	Paraffins and Naphthenes (mac 500–1000 ppm) (3)	Boiling Range (° C)
Pentol O. D. Enamel Thinner	20	10	70	
Phenolic Thinner		100		
Pittsburgh Minimax		36	64	
Pyroxyline Thinner	4	55	41	
Red Lacquer Thinner	15	50	35	68–145
Reducer 74			100	145–205
Sea Lac Lacquer Thinner	30	40	30	65–130
Sewell 3551 Paint Thinner	75		25	134–175
Sherwin-Williams Paint Thinner	5		95	64–130
Sol Naphtha			100	160–194
Solox		100		77–107
Solvesso 1 Thinner	60		40	85–135
Solvesso 3	70		30	170–220
Solvesso—Sohio 1	70		30	90–140
Special Fast Dry Stencil Thinner	18		82	111–141
Spruance Thinner	7	55	38	68–140
Stencil Thinner Solvent 50	25	65	10	50–195
Superior 77 Ink Thinner		100		80–200
Synthetic Enamel Thinner	40		60	135–200
Synthetic Thinner for O. D. Paint			100	90–145
Synthetic Thinner—Latex		60	40	70–165
Thinner 30	60	40		56–125
Thinner 74			100	160–210
Thinner, Acid Proof Black Paint	15		85	120–147
Thinner, Cooks	20	50	30	
Thinner, G. E. 1500	70		30	105–145
Thinner, Lacquer 20	22	52	26	69–153
Thinner, Lacquer (du Pont) (3-162-1)	21	32	47	

TABLE C (*Continued*)

APPROXIMATE COMPOSITION OF SOME ORGANIC SOLVENTS USED AS THINNERS

Name or Trade Name of Product	Composition (Per Cent)			Boiling Range (° C)
	Aromatics (mac 50–200 ppm) (1)	Alcohols, Esters, Ethers, and Ketones (mac 200–400 ppm) (2)	Paraffins and Naphthenes (mac 500–1000 ppm) (3)	
Thinner, Lacquer Enamel (3–162–A)	20	50	30	70–130
Thinner, Lacquer Enamel (Cooks)	34		66	67–141
Thinner, Lacquer Enamel (Nitro Cellulose)		60	40	
Thinner, Marking Ink 4		100		124
Thinner—Paint (76)	10	65	25	
Thinner, Pedigree 150	100			133–151
Thinner, Testor's	26	33	41	
Thinner, Witte's Lacquer Thinner	26	30	44	82–124
V. M. & P. Naphtha	5		95	98–176
Warren's Deodorized Leptine			100	165–210
Wash 5816 Thinner	10	75	15	70–140
Westinghouse 8110 Thinner		100		73–107
Westinghouse Tuffernell Thinner 1609	3		97	155–196
Xylol Solvesso	100			135–180
Zapon Cotite A	15	80	5	70–130

1. AROMATICS. These materials are very toxic. The common ones have maximum allowable concentrations of 50 to 200 ppm. Examples are benzene, toluene, and xylene.

2. ALCOHOLS, ESTERS, ETHERS, AND KETONES. These chemical groups are less toxic than 1. Most of those encountered in the samples analyzed fall into a maximum allowable concentration toxicity range of 200 to 400 ppm. Examples are acetone, methyl ethyl ketone, the alcohols, and the acetates.

3. PARAFFINS AND NAPHTHENES. This group is not particularly toxic. It includes materials such as gasoline, Stoddard solvent, petroleum naphtha, and V M and P naphtha. The maximum allowable concentrations for the materials in this group range from 500 to 1000 ppm.

TABLE D

Approximate Composition of Some Organic Solvents Used for Cleaning or Degreasing Operations

Name or Trade Name of Product	Composition (Per Cent)					Boiling Range (° C)
	Aromatics (mac 50–200 ppm) (1)	Halogenated Hydrocarbons (mac 50–200 ppm) (2)	Alcohols, Esters, Ethers, and Ketones (mac 200–400 ppm) (3)	Paraffins and Naphthenes (mac 500–1000 ppm) (4)	Other	
Actusol (grease solvent)				100		155–205
Amercoat 10	29		58	13		110–158
Amercoat 12	27		64	9		58–164
APCO–140				100		180–220
Ber-to-sol	5	60		35		84–144
Blankrola	9	45		46		128–175
Casite Sludge Solvent	45			55		170–260
CC Sol	10		17	73		80–146
Cellosolve Acetate			100			155–158
Cleaners Naphtha				100		155–220
Cleaning Fluid				100		145–200
Colonel Speedy Carbon and Rust Remover			45		Water	70–100
Dearboline Cleaning Compound				100		185–300
Degreasal		100				70–110
Degreasal Hi T				100		160–222
Ditto Fluid			100			78 app.
Dry Cleaners Solvent				100		156–196
Dry Cleaning Fluid		25		75		75–140
Dry Cleaning Solvent				100		160–205
Dry Cleaning Solvent (PS 661A)				100		145–210
Finger Print Remover				100		
Gas-O-Clenz				100		80–150
Hylite				100		55–175
Imperial Washer Cleaner	20	70		10		75–120
Ink Cleaner 77			80	20		75–235
Keelite Z. C. Stripper	25		65	10		60–135
Kerosene				100		
Kleen-O-Type	35	65				75– 80
Lacquer Thinner CT–350	16		47	37		78–134
Lithotine				100		150–210
Loosite	30		8	62		60–270
Magnolia Sovalsol				100		160–200
Magnus Carbon Remover		55			Cresylic acid	
Magnusol				100		130–190
Mineral Spirits				100		150–200
Mineral Spirits 12				100		160–210
Naphtha, Cleaners				100		155–220

TABLE D (*Continued*)

Approximate Composition of Some Organic Solvents Used for Cleaning or Degreasing Operations

Name or Trade Name of Product	Composition (Per Cent)					Boiling Range (° C)
	Aromatics (mac 50–200 ppm) (1)	Halogenated Hydrocarbons (mac 50–200 ppm) (2)	Alcohols, Esters, Ethers, and Ketones (mac 200–400 ppm) (3)	Paraffins and Naphthenes (mac 500–1000 ppm) (3)	Other	
Naphtha, V M and P	11			89		112–141
Nu-film 22	10		70	20		65–140
O'Brien Lacquer Thinner L–156–XX	3		40	57		
Paco Solvent (denatured alcohol)			100			75–100
Paint and Varnish Remover	50		50			64– 75
Penotrite		20		80		139–186
Ponsolve			100			73– 79
Rifle Bore Cleaner				80	Water	76–260
Shamrock Solvent				100		160–200
Shellacol			100			78 app.
Solvasol 5 (Varnoline)				100		160–190
Solvental				94	Soap	185–245
Sovalsol, Magnolia				100		160–200
Stanisol Solvent Mixture				100		150–200
Stoddard Solvent				100		157–188
Stoddard Solvent				100		150–200
Stoddard Solvent				100		145–195
Synosol			100			84 app.
Testors Thinner			60	40		60–110
Tomac Thinner				100		60–210
Tri Sol		45		55		82–209
Type Wash	39		38	23		64–142
Varnish and Paint Remover	50		50			64– 75
Varsol				100		150–200
V M and P Naphtha	11			89		112–141
Washurite		25	5	70		61–170

1. Aromatics. These materials are very toxic. The common ones have maximum allowable concentrations of 50 to 200 ppm. Examples are benzene, toluene, and xylene.

2. Halogenated hydrocarbons. These chemicals also are very toxic. Most of those encountered in the group of samples analyzed have maximum allowable concentrations in the range of 50 to 200 ppm. Examples are carbon tetrachloride, trichloroethylene, and dichlorobenzene.

3. Alcohols, esters, ethers, and ketones. These chemical groups are less toxic than 1 and 2. Most of those encountered in the samples analyzed fall into a maximum allowable concentration toxicity range of 200 to 400 ppm. Examples are acetone, methyl ethyl ketone, the alcohols, and the acetates.

4. Paraffins and naphthenes. This group is not particularly toxic. It includes materials such as gasoline, Stoddard solvent, petroleum naphtha, and V M and P naphtha. The maximum allowable concentrations for the materials in this group range from 500 to 1000 ppm.

TABLE E

RECOMMENDED EXHAUST VOLUMES AND CONVEYING VELOCITIES FOR A VARIETY OF CONTAMINANT-PRODUCING EQUIPMENT

Contaminant-Producing Equipment	*Exhaust Hood*	*Exhaust Requirements*	*Conveying Velocities in Feet per Minute*		*References and Notes*
			Branch	*Main*	
Abrasive blast rooms (sand, grit, or shot)	Tight enclosure with air inlets (usually in roof)	60–100 fpm downdraft (long rooms of tunnel proportions 100 fpm crossdraft)	4500	4500	Exhaust volume should be sufficient to provide visibility for operator. Sand as abrasive or castings with cores or heavy-molding sand deposits require highest range; AFA, N. Y. and Illinois specify 80 fpm downdraft minimum for all cases (see Chapter X)
Abrasive blast cabinets	Tight enclosure with access openings	20 air changes per minute, but not less than 500 fpm through all openings	4500	4500	AFA Code (see Chapter X)
Bagging machines	Booth or enclosure (provide spillage hopper)	Paper bags—100 cfm per square foot open area; cloth bags—200 cfm per square foot open area	4000	4000	New York Code 34 for silica dust in stone-crushing operations
Barrels (for filling or removing material)	Local hood, 120 degrees around top of barrel	Through 24-in. diameter—4-in. branch; over 24-in. diameter—5-in. branch	4000	4000	
Belt conveyors	Hoods at transfer point	Belt speeds less than 200 fpm—350 cfm per foot of belt width, but not less than 150 fpm through open area; belt speeds over 200 fpm—500 cfm per foot of	4000	4000	New York Code 10 and 34; Illinois Code specifies 300 cfm per foot of belt width. "Foundry Dust Control," *The Foundry*, January 1938.

TABLE E (*Continued*)

RECOMMENDED EXHAUST VOLUMES AND CONVEYING VELOCITIES FOR A VARIETY OF CONTAMINANT-PRODUCING EQUIPMENT

Contaminant-Producing Equipment	*Exhaust Hood*	*Exhaust Requirements*	*Conveying Velocities in Feet per Minute* Branch	Main	*References and Notes*
		belt width, but not less than 200 fpm through open area			
Belt wipers (may be required with high-speed belts)	Tight-fitting hood held against under side of belt	200 cfm per foot of belt width	4000	4000	Requires high hood suction and high conveying velocities; mechanical brushing or wiping often used in conjunction with hood
Bins (closed bin top)	Connect to bin top away from feed point	150–200 fpm through open area at feed points, but not less than 0.5 cfm per cubic foot of bin capacity	4000	4000	
Bucket elevators	Tight casing required	100 cfm per square foot of elevator casing cross section (exhaust from elevator head)	4000	4000	To maintain indraft in casing only; additional exhaust at elevator boot and discharge unless tight connections are employed
Ceramics					
Dry pan	Local hoods	See Mixers	4000	4000	
Dry press	Local hoods	Automatic feed, 1–5-in.-diameter branch at die; manual feed, 1–5-in.-diameter branch at supply bin; 1–5-in.-diameter branch at die	4000	4000	
Degreasing Tanks	Slot hoods	50 cfm per square foot of tank area	2000	2000	Ventilation usually not needed if tanks are operated properly (see Chapters X and XI)

Tables	Downdraft or lateral exhaust hoods	Minimum of 100 fpm over area of contaminant escape	2000	2000	(See Chapters X and XI)
Fettling, brushing, sagger filling, and unloading	Downdraft or side hood	100–150 cfm per square foot of plan area of dust-producing operation	3500	3500	
Finishing tanks	Slot hoods				(See Chapter XI)
Grinders: polishing, buffing, etc.	Standard-wheel hood		4500	4500	AFA, New York and Illinois Codes (see Chapters X and XI)
Grinders: swing frame	Booth	100–150 fpm indraft through opening in booth face	3000	3000	"Swing Frame Grinder Dust Control," *The Foundry*, August 1944 (see Chapter XI and Appendix, Figure VII)
Grinders: portable and flexible shaft	Downdraft grilles; use side shields where possible	Bench type, 200–400 cfm per square foot of exhaust grille, but not less than 150 cfm per square foot of plan working area	3500	3500	New York Code says not less than 100 cfm per square foot of gross working area (see Chapter XI and Appendix, Figures V and VI)
		Floor grille, 200–400 cfm per square foot of exhaust grille, but not less than 100 cfm per square foot of plan working area	3500	3500	
Mixer	Enclosure	100–200 fpm through working and inspection openings	3500	3500	Where mixer causes pronounced agitation, use indraft velocities in the higher range listed
Pharmaceuticals: coating pans	Narrow side hood	Through 16-in. opening—200 cfm; over 16 in. through 22 in.—300 cfm; over 22 in. through 26 in.—400 cfm	3000	3000	Assumes no heated air supplied to coating pan; increase exhaust volume by cfm of heated air where supplied

TABLE E (*Continued*)

RECOMMENDED EXHAUST VOLUMES AND CONVEYING VELOCITIES FOR A VARIETY OF CONTAMINANT-PRODUCING EQUIPMENT

Contaminant-Producing Equipment	*Exhaust Hood*	*Exhaust Requirements*	*Conveying Velocities in Feet per Minute* Branch	Main	*References and Notes*
Screens: vibrating, flat deck	Enclosure	150–200 fpm indraft through hood openings, but not less than 25–50 cfm per square foot of screen area	4000	4000	Use single deck area where screen has two or more decks
Cylindrical	Enclosure	100 cfm per square foot of circular cross section, but not less than 400 fpm indraft through openings in enclosure	4000	4000	
Shakeouts: foundry	Enclosure	200 fpm through all openings in enclosure, but not less than 200 cfm per square foot of grate area	4000	4000	New York and Illinois Codes
	Side hood (use side shields whenever possible)	400–600 cfm per square foot of shakeout grate area	4000	4000	New York and Illinois Codes use minimum of 275 cfm per square foot of grate area where two sides are shielded and hood extends over not less than ⅓ of grate area (see Appendix, Figures VIII and IX)
Tumbling mills					
Hollow-trunnion type	Exhaust connection by manufacturer	Use branch diameter same size as exhaust outlet; for round mills branch diam-	5000	4000	AFA, New York, and Illinois Codes specify 5000 fpm in branches (see Chapter XI)

		eter should be $\frac{1}{6}$ diameter of mill; for square mills, branch diameter should be 1 in. plus $\frac{1}{6}$ side dimension of mill			
Stave type	Enclosure		5000	4000	New York Code 10 (see Chapter XI)
Woodworking			4000	3500	(See Chapters X and XI)
Miscellaneous					
Packaging machines, granulators, enclosed dust-producing units	Complete enclosure	100–400 fpm indraft through inspection or working openings, but not less than 25 cfm per square foot of enclosed plan area	3000	3000	Volume will normally be insufficient to prevent dust settling on floor and equipment within enclosure
Packaging, weighing, container filling, inspection	Booth	50–150 cfm per square foot face area	3000	3000	
	Downdraft	75–150 cfm per square foot of dust-producing plan area	3500	3500	

TABLE F

THE MORE IMPORTANT CHEMICAL ELEMENTS WITH THEIR SYMBOLS AND ATOMIC WEIGHTS *

Element	Symbol	Atomic Weight	Element	Symbol	Atomic Weight
Aluminum	Al	26.97	Manganese	Mn	54.93
Antimony	Sb	121.77	Mercury	Hg	200.61
Argon	A	39.91	Molybdenum	Mo	96.0
Arsenic	As	74.96	Neon	Ne	20.2
Barium	Ba	137.37	Nickel	Ni	58.69
Bismuth	Bi	209.0	Nitrogen	N	14.008
Boron	B	10.82	Osmium	Os	190.8
Bromine	Br	79.92	Oxygen	O	16.000
Cadmium	Cd	112.41	Palladium	Pd	106.7
Calcium	Ca	40.07	Phosphorus	P	31.027
Carbon	C	12.000	Platinum	Pt	195.23
Cerium	Ce	140.25	Potassium	K	39.096
Cesium	Cs	132.81	Radium	Ra	225.95
Chlorine	Cl	35.46	Radon	Rn	222.
Chromium	Cr	52.01	Rhodium	Rh	102.91
Cobalt	Co	58.94	Selenium	Se	79.2
Copper	Cu	63.57	Silicon	Si	28.06
Fluorine	F	19.0	Silver	Ag	107.880
Gold	Au	197.2	Sodium	Na	22.997
Helium	He	4.00	Strontium	Sr	87.63
Hydrogen	H	1.008	Sulfur	S	32.064
Iodine	I	126.932	Thorium	Th	232.15
Iridium	Ir	193.1	Tin	Sn	118.70
Iron	Fe	55.84	Titanium	Ti	48.1
Krypton	Kr	82.9	Tungsten	W	184.0
Lanthanum	La	138.90	Uranium	U	238.17
Lead	Pb	207.20	Vanadium	V	50.96
Lithium	Li	6.940	Zinc	Zn	65.38
Magnesium	Mg	24.32	Zirconium	Zr	91.22

* From the International Table of Atomic Weights for 1925.

TABLE G

Condensed Table of Logarithms of Numbers

No.	Log.	No.	Log.	No.	Log.	No.	Log.	No.	Log.	No.	Log.
1000	0000	1100	0414	1300	1139	1500	1761	2500	3979	5000	6990
1002	0009	1104	0430	1304	1153	1520	1818	2550	4065	5100	7076
1004	0017	1108	0445	1308	1166	1540	1875	2600	4150	5200	7160
1006	0026	1112	0461	1312	1179	1560	1931	2650	4232	5300	7243
1008	0035	1116	0477	1316	1193	1580	1987	2700	4314	5400	7324
1010	0043	1120	0492	1320	1206	1600	2041	2750	4393	5500	7404
1012	0052	1124	0508	1324	1219	1620	2095	2800	4472	5600	7482
1014	0060	1128	0523	1328	1232	1640	2148	2850	4548	5700	7559
1016	0069	1132	0538	1332	1245	1660	2201	2900	4624	5800	7634
1018	0077	1136	0554	1336	1258	1680	2253	2950	4698	5900	7708
1020	0086	1140	0569	1340	1271	1700	2304	3000	4771	6000	7782
1022	0095	1144	0584	1344	1284	1720	2355	3050	4843	6100	7853
1024	0103	1148	0599	1348	1297	1740	2405	3100	4914	6200	7924
1026	0111	1152	0615	1352	1310	1760	2455	3150	4983	6300	7993
1028	0120	1156	0630	1356	1323	1780	2504	3200	5052	6400	8062
1030	0128	1160	0645	1360	1335	1800	2553	3250	5119	6500	8129
1032	0137	1164	0660	1364	1348	1820	2601	3300	5185	6600	8195
1034	0145	1168	0674	1368	1361	1840	2648	3350	5250	6700	8261
1036	0154	1172	0689	1372	1374	1860	2695	3400	5315	6800	8325
1038	0162	1176	0704	1376	1386	1880	2742	3450	5378	6900	8388
1040	0170	1180	0719	1380	1398	1900	2788	3500	5441	7000	8451
1042	0179	1184	0734	1384	1411	1920	2833	3550	5502	7100	8513
1044	0187	1188	0748	1388	1424	1940	2878	3600	5563	7200	8573
1046	0195	1192	0763	1392	1436	1960	2923	3650	5623	7300	8633
1048	0204	1196	0777	1396	1449	1980	2967	3700	5682	7400	8692
1050	0212	1200	0792	1400	1461	2000	3010	3750	5740	7500	8751
1052	0220	1204	0806	1404	1474	2020	3054	3800	5798	7600	8808
1054	0228	1208	0821	1408	1486	2040	3096	3850	5855	7700	8865
1056	0237	1212	0835	1412	1498	2060	3139	3900	5911	7800	8921
1058	0245	1216	0849	1416	1511	2080	3181	3950	5966	7900	8976
1060	0253	1220	0863	1420	1523	2100	3222	4000	6021	8000	9031
1062	0261	1224	0878	1424	1535	2120	3263	4050	6075	8100	9085
1064	0269	1228	0892	1428	1547	2140	3304	4100	6128	8200	9138
1066	0278	1232	0906	1432	1559	2160	3345	4150	6180	8300	9191
1068	0286	1236	0920	1436	1572	2180	3385	4200	6232	8400	9243
1070	0294	1240	0934	1440	1584	2200	3424	4250	6284	8500	9294
1072	0302	1244	0948	1444	1596	2220	3464	4300	6335	8600	9345
1074	0310	1248	0962	1448	1608	2240	3502	4350	6385	8700	9395
1076	0318	1252	0976	1452	1620	2260	3541	4400	6435	8800	9445
1078	0326	1256	0990	1456	1632	2280	3579	4450	6484	8900	9494
1080	0334	1260	1004	1460	1644	2300	3617	4500	6532	9000	9542
1082	0342	1264	1017	1464	1655	2320	3655	4550	6580	9100	9590
1084	0350	1268	1031	1468	1667	2340	3692	4600	6628	9200	9638
1086	0358	1272	1045	1472	1679	2360	3729	4650	6675	9300	9685
1088	0366	1276	1059	1476	1691	2380	3766	4700	6721	9400	9731
1090	0374	1280	1072	1480	1703	2400	3802	4750	6767	9500	9777
1092	0382	1284	1086	1484	1714	2420	3838	4800	6812	9600	9823
1094	0390	1288	1099	1488	1726	2440	3874	4850	6857	9700	9868
1096	0398	1292	1113	1492	1738	2460	3909	4900	6902	9800	9912
1098	0406	1296	1126	1496	1749	2480	3945	4950	6946	9900	9956

TABLE H

Condensed Table of Natural Trigonometric Functions

Angle (degrees)	Sine	Cosine	Tangent	Angle (degrees)	Sine	Cosine	Tangent
0	0.0000	1.0000	0.0000	45	0.7071	0.7071	1.0000
1	0.0175	0.9998	0.0175	46	0.7193	0.6947	1.0355
2	0.0349	0.9994	0.0349	47	0.7314	0.6820	1.0724
3	0.0523	0.9986	0.0524	48	0.7431	0.6691	1.1106
4	0.0698	0.9976	0.0699	49	0.7547	0.6561	1.1504
5	0.0872	0.9962	0.0875	50	0.7660	0.6428	1.1918
6	0.1045	0.9945	0.1051	51	0.7771	0.6293	1.2349
7	0.1219	0.9925	0.1228	52	0.7880	0.6157	1.2799
8	0.1392	0.9903	0.1405	53	0.7986	0.6018	1.3270
9	0.1564	0.9877	0.1584	54	0.8090	0.5878	1.3764
10	0.1736	0.9848	0.1763	55	0.8192	0.5736	1.4281
11	0.1908	0.9816	0.1944	56	0.8290	0.5592	1.4826
12	0.2079	0.9781	0.2126	57	0.8387	0.5446	1.5399
13	0.2250	0.9744	0.2309	58	0.8480	0.5299	1.6003
14	0.2419	0.9703	0.2493	59	0.8572	0.5150	1.6643
15	0.2588	0.9659	0.2679	60	0.8660	0.5000	1.7320
16	0.2756	0.9612	0.2867	61	0.8746	0.4848	1.8040
17	0.2924	0.9563	0.3057	62	0.8829	0.4695	1.8807
18	0.3090	0.9511	0.3249	63	0.8910	0.4540	1.9626
19	0.3256	0.9455	0.3443	64	0.8988	0.4384	2.0503
20	0.3420	0.9397	0.3640	65	0.9063	0.4226	2.1445
21	0.3584	0.9336	0.3839	66	0.9135	0.4067	2.2460
22	0.3746	0.9272	0.4040	67	0.9205	0.3907	2.3559
23	0.3907	0.9205	0.4245	68	0.9272	0.3746	2.4751
24	0.4067	0.9135	0.4452	69	0.9336	0.3584	2.6051
25	0.4226	0.9063	0.4663	70	0.9397	0.3420	2.7475
26	0.4384	0.8988	0.4877	71	0.9455	0.3256	2.9042
27	0.4540	0.8910	0.5095	72	0.9511	0.3090	3.0777
28	0.4695	0.8829	0.5317	73	0.9563	0.2924	3.2709
29	0.4848	0.8746	0.5543	74	0.9613	0.2756	3.4874
30	0.5000	0.8660	0.5774	75	0.9659	0.2588	3.7321
31	0.5150	0.8572	0.6009	76	0.9703	0.2419	4.0108
32	0.5299	0.8480	0.6249	77	0.9744	0.2250	4.3315
33	0.5446	0.8387	0.6494	78	0.9781	0.2079	4.7046
34	0.5592	0.8290	0.6745	79	0.9816	0.1908	5.1446
35	0.5736	0.8192	0.7002	80	0.9848	0.1736	5.6713
36	0.5878	0.8090	0.7265	81	0.9877	0.1564	6.3136
37	0.6018	0.7986	0.7536	82	0.9903	0.1392	7.1154
38	0.6157	0.7880	0.7813	83	0.9925	0.1219	8.1443
39	0.6293	0.7771	0.8098	84	0.9945	0.1045	9.5144
40	0.6428	0.7660	0.8391	85	0.9962	0.0872	11.4300
41	0.6561	0.7547	0.8693	86	0.9976	0.0698	14.3007
42	0.6691	0.7431	0.9004	87	0.9986	0.0523	19.0811
43	0.6820	0.7314	0.9325	88	0.9994	0.0349	28.6363
44	0.6947	0.7193	0.9657	89	0.9998	0.0175	57.2900

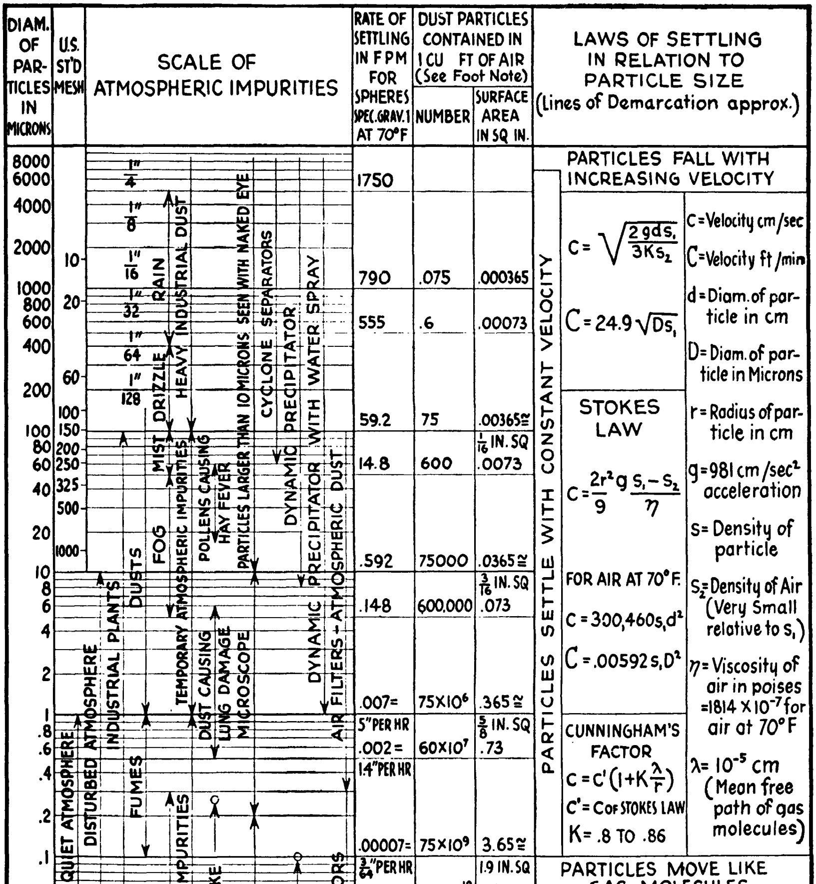
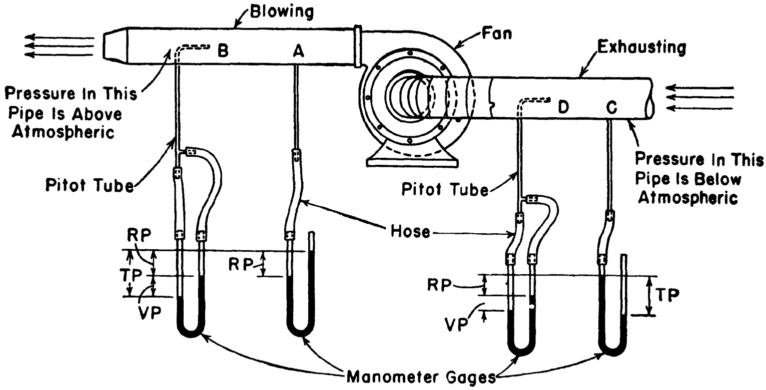


FIGURE I. Size and Characteristics of Air-Borne Particulate Matter. (It is assumed that the particles are of uniform spherical shape having specific gravity of 1.0 and that the dust concentration is 0.6 grains per 1000 cu ft of air, the average of metropolitan districts) (*Courtesy W. G. Frank*)



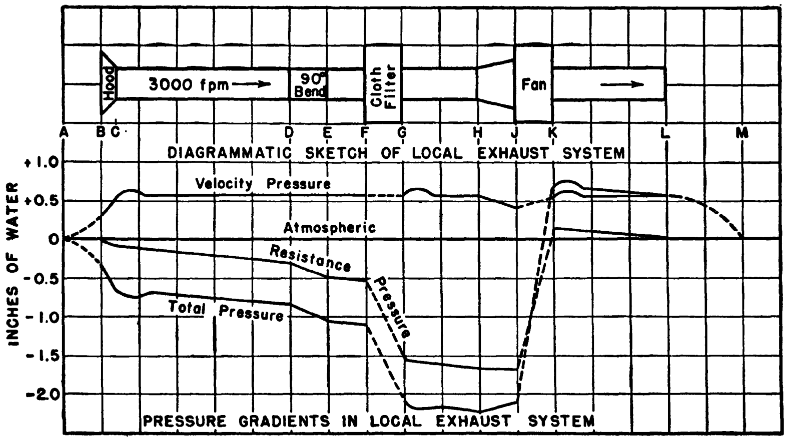
Blowing System	Exhausting System
Manometer reading taken at *A* indicates resistance pressure (+*RP*). Note: (+*RP*) in a blowing system is often referred to as static pressure. Pitot tube manometer reading taken at *B* indicates velocity pressure (+*VP*). The total pressure (+*TP*) is the sum of $+VP + RP = +TP$. The total pressure *TP* may be obtained by the use of an impact tube.	Manometer reading taken at *C* indicates total pressure (−*TP*). Note: (−*TP*) in an exhausting system is often referred to as static pressure. Pitot tube manometer reading taken at *D* indicates velocity pressure (+*VP*). The resistance pressure (−*RP*) is the algebraic sum of $-TP + VP = -RP$. The resistance pressure (−*RP*) may be obtained by the use of an impact tube.

Notes: The measurements (+*RP*) in blowing systems and (−*TP*) in exhausting systems shall be made by placing the manometer hose connections over a small hole in the pipe at right angles to the air flow. The edges of the hole must be free from burrs, and the hose must not extend into the air stream.

The (+*VP*) in both blowing and exhausting systems must be determined by traversing accurately the pipe cross section to obtain the mean velocity pressure. See Chapter IX.

(Courtesy AFA)

Figure II. Pressure Terminology in a Ventilating System



Velocity pressure (*VP*) is the pressure required to accelerate air from a state of rest to the particular velocity required. The velocity pressure is measured with a Pitot tube and manometer in a similar manner in either blowing or exhaust systems. Its numerical value is always positive.

Resistance pressure (*RP*) is the pressure required to overcome the resistance of the system. It includes the resistance of straight runs of pipe, entrance to headers, bends, elbows, orifice loss, and cleaning device. In an exhausting system it is indicated by the algebraic sum of the total pressure as measured with a manometer gage and the velocity pressure as measured with a Pitot tube, and its numerical value is always negative ($-RP = -TP + VP$). In a blowing system the resistance pressure is indicated by a direct manometer gage reading, and its numerical value is always positive ($RP = TP - VP$).

Total pressure (*TP*) is the pressure necessary to overcome the resistance pressure (*RP*) and maintain the required velocity pressure (*VP*). In an exhausting system it is indicated by a manometer gage reading and is negative in numerical value, and it is the sum of the resistance pressure (*RP*) and velocity pressure (*VP*) regardless of signs ($-TP = RP + VP$). In a blowing system the total pressure (*TP*) is numerically positive in value and is the sum of the resistance pressure (*RP*) and the velocity pressure (*VP*) or ($TP = RP + VP$).

NOTE: See Figure II for a diagrammatic explanation of the various pressure terminologies.

FIGURE III

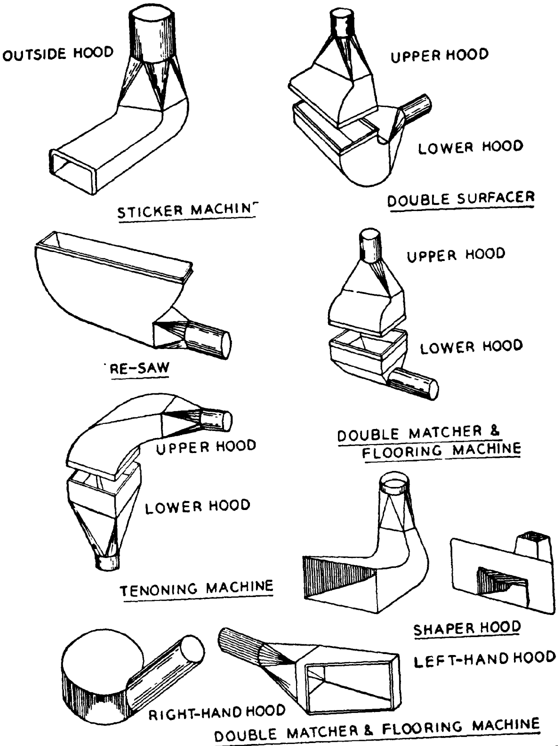


FIGURE IV. Typical Hoods for Woodworking Operations (*Courtesy J. M. Kane*)

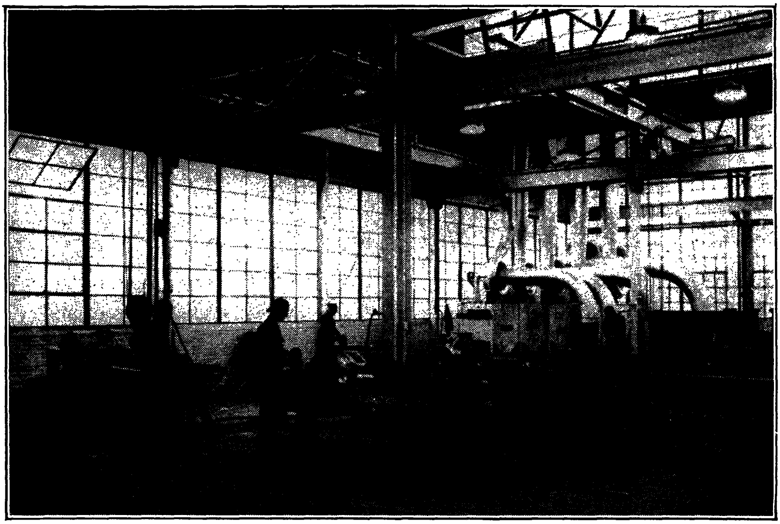


FIGURE V. Downdraft Floor Grills at Grinding and Finishing Operations on Large Castings (*Courtesy American Air Filter Co.*)

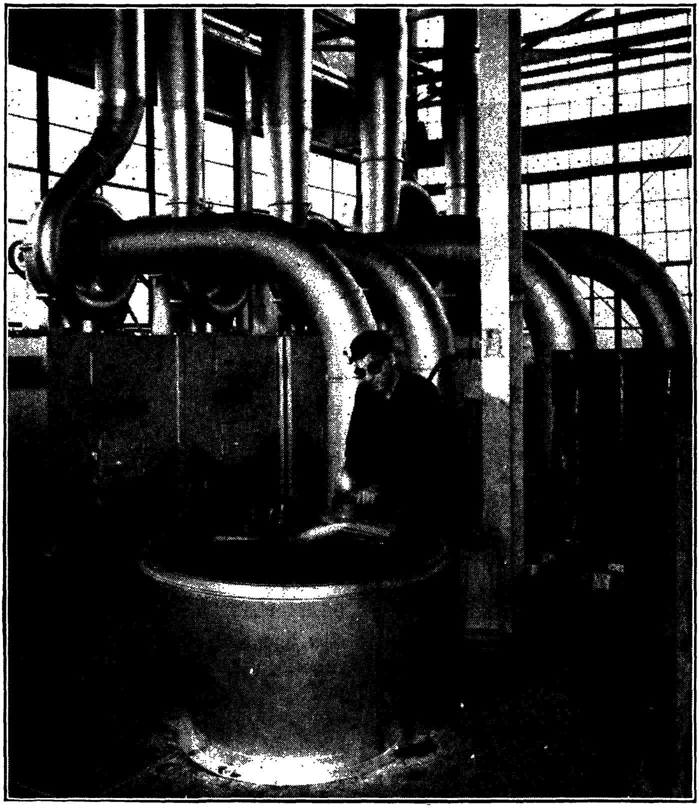


FIGURE VI. Downdraft Bench-Type Hood for Grinding Operations on Small Objects (*Courtesy American Air Filter Co.*)

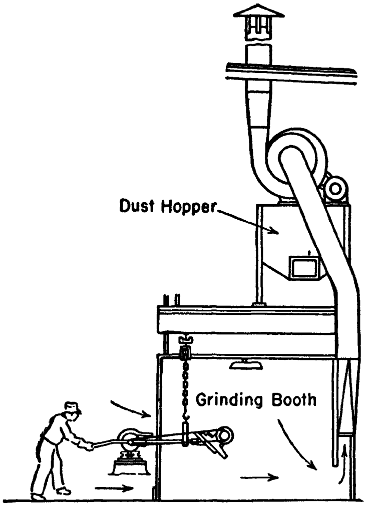


FIGURE VII. Schematic Sketch of Dust-Control Installation for Swing-Frame Grinders (*Courtesy American Air Filter Co.*)

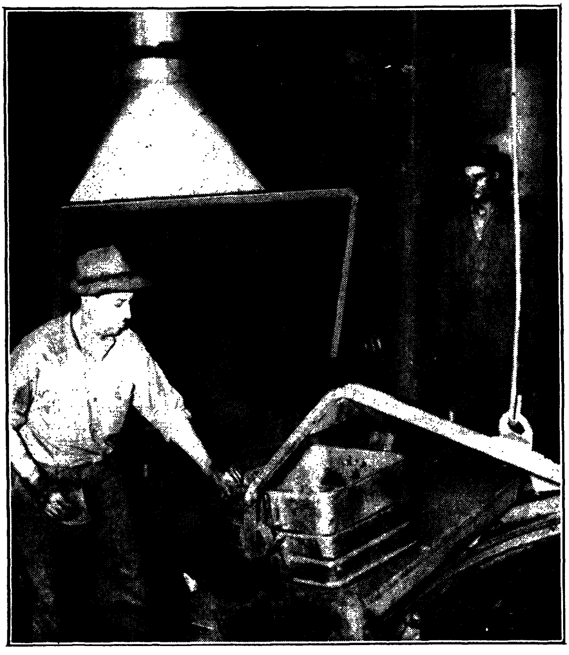


FIGURE VIII. Dust-Control Hood at Small Casting Shakeout (*Courtesy American Air Filter Co.*)

FIGURE IX. Side-Draft Hood for Shaking Out Large Castings (*Courtesy American Air Filter Co.*)

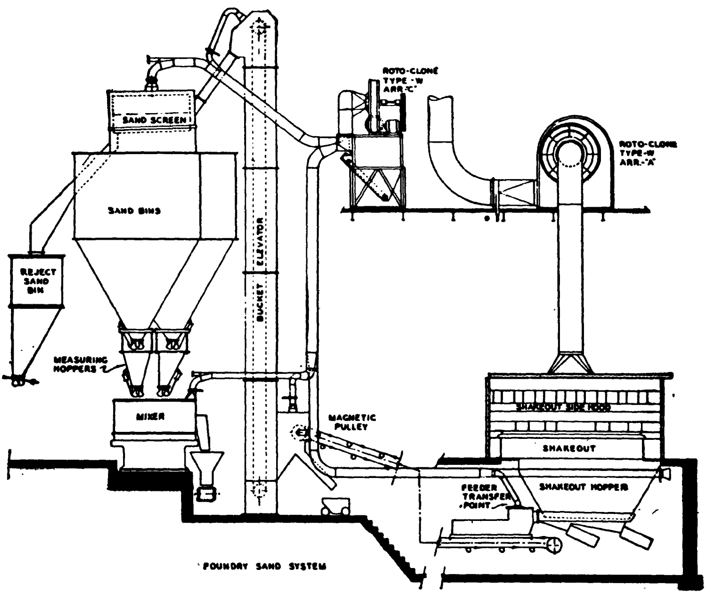


FIGURE X. Schematic Diagram of Dust Control at Mechanical Sand-Handling System for Foundries (*Courtesy American Air Filter Co.*)

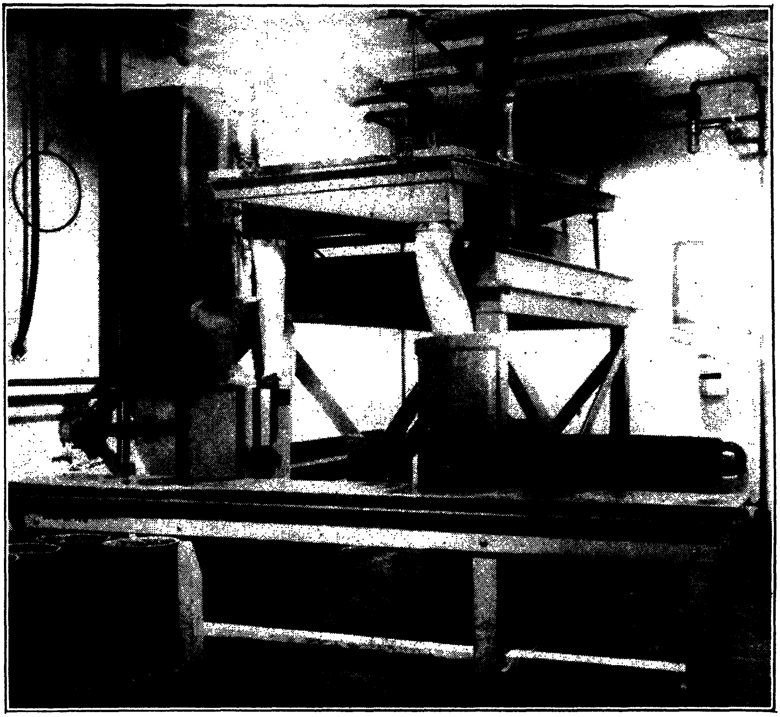


FIGURE XI. Wet Collector Located at Hood Handling an Explosive Contaminant

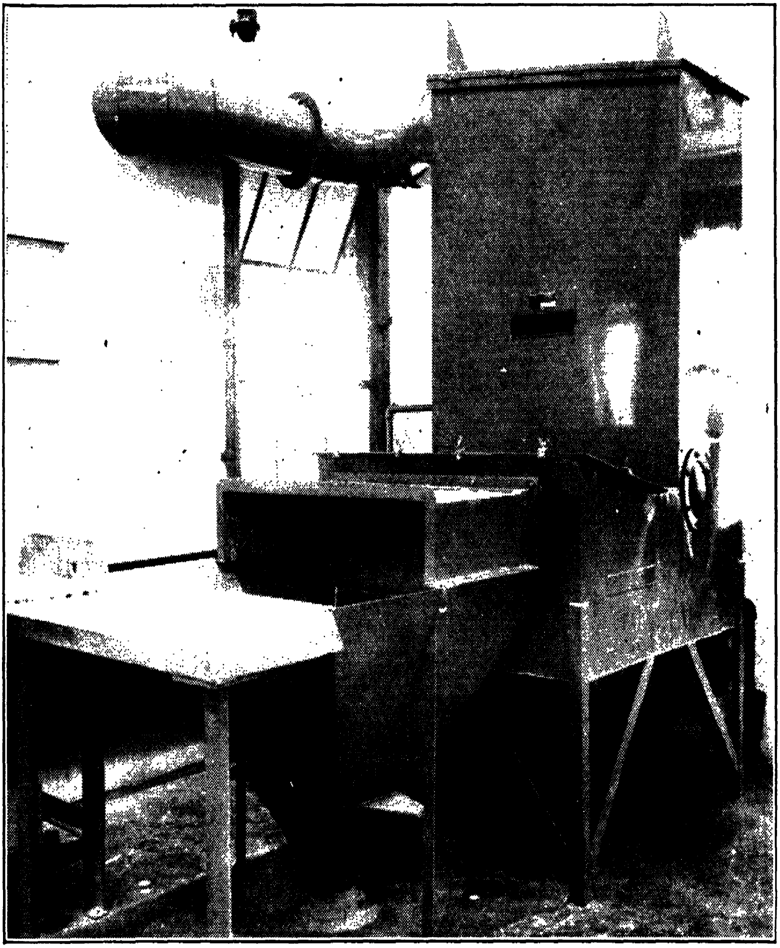


FIGURE XII. Wet Collector at Hood Exhausting an Explosive Contaminant

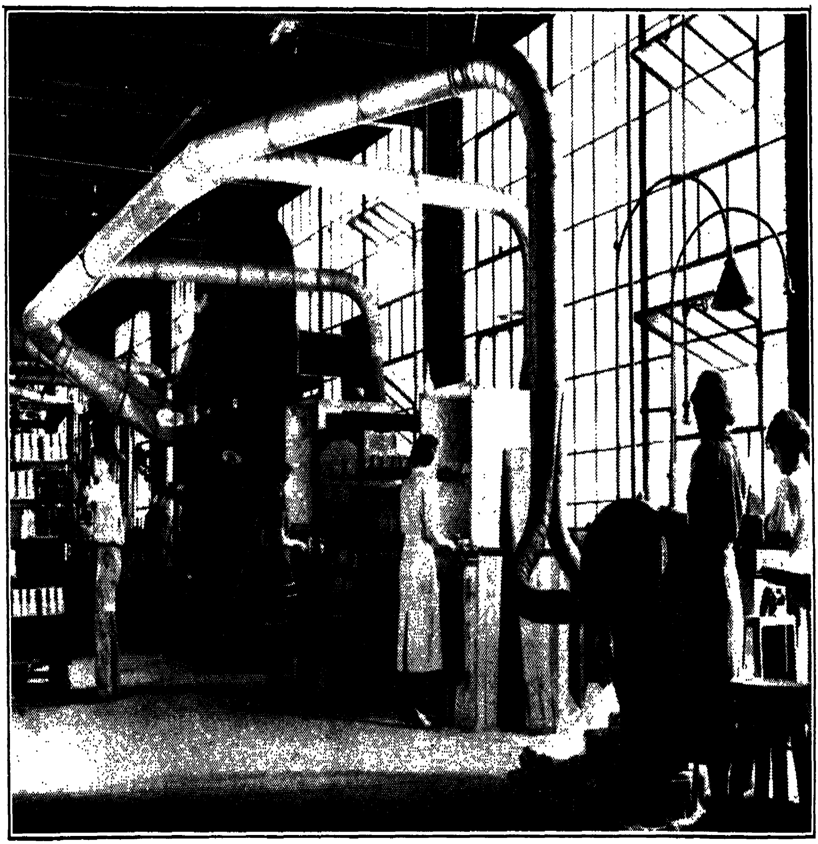


FIGURE XIII. Example of Well-Designed Ductwork

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